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CENTRAL MISSOURI RIVER WATER QUALITY INVESTIGATION, AUGUST 1952-DECEMBER 1953

Public Health Service
Kansas City, Missouri

April 1954

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U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
PUBLIC HEALTH SERVICE
DIVISION OF WATER POLLUTION CONTROL
MISSOURI DRAINAGE BASIN

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U. S. Department of Health, Education and Welfare

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Division of Water Pollution Control

Missouri Drainage Basin

Kansas City, Missouri

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SUMMARY

1. This investigation, directed by the Missouri Drainage Basin Office of the U. S. Public Health Service, was a cooperative project with the Missouri River Division, Corps of Engineers, the State Health Departments of Iowa, Nebraska, South Dakota, and North Dakota, the Wyoming Department of Public Health, and water works personnel at Council Bluffs, Iowa, Omaha, Nebraska, Yankton, and Chamberlain, South Dakota.

2. The first 17 months (August, 1952 - December, 1953) of the study are reported herein. Data presented and discussed cover certain physical, chemical, and biological aspects of the Missouri River (Williston, North Dakota, to Omaha, Nebraska) and their interrelationships for 11 months before and 6 months after significant impoundment in Fort Randall Reservoir.

3. Discharge in the main stem was increased by snow melt and rainfall, and regulated to a large extent during seasons of lesser runoff by releases from Fort Peck and, in late 1953, Fort Randall Reservoirs. Impoundment of Fort Randall Reservoir included segments of discharge over an extended period and no particular retention of any seasonal runoff.

4. Turbidity varied with seasonal phenomena, discharge, ice cover, etc.; and was greatly reduced, at least down to Omaha, Nebr. after early July 1953, by impoundment at Fort Randall Dam. Major contributors of turbid particles were surface runoff and bank erosion.

5. Chemical features also varied in accord with seasonally induced changes in discharge, water temperature, ice cover, turbidity, etc. Sampling stations were so located to exclude or minimize effects

of local pollution at each municipality; and chemical analyses should not be considered demonstrative of influences of heavy pollutional discharges in the stretch below Sioux City, Iowa, but rather indicative of the best conditions prevailing in that reach.

Phytoplankton influences upon water chemistry were not apparent for any extended period of time prior to impoundment of Fort Randall Reservoir. However, following turbidity reduction by this reservoir, their photosynthetic activities were instrumental in lowering and making more uniform hardness and alkalinity concentrations.

6. Plankton concentrations, except for a brief period in May and early June, 1953, were quite low until clear water was available in and below Fort Randall Reservoir, after which their density greatly increased, reaching nuisance levels in water supplies at Yankton in August 1953. Benthic algal growths, absent before impoundment, became prominent below Fort Randall Dam after July, 1953. The Missouri River developed a characteristic phytoplankton population from a variety of assemblages entering it from various tributaries; and this characteristic was not qualitatively modified by the presence of the reservoir in 1953. Diatoms were usually dominant plankters at each station over the greater part of the year. Chlamydomonas was frequently the most numerous group in colder seasons.

7. Investigation of Missouri River water caught in oxbows and pumped into settling basins at Council Bluffs, Iowa, offered little information pertinent to the Fort Randall Reservoir situation. However, the settling basin studies demonstrated a high productivity potential of river water in the Omaha-Council Bluffs area.

8. Phytoplankton and other algal growths related to impoundment

of Boysen Reservoir on the Big Horn River in Wyoming resembled in some respects developments associated with Fort Randall Reservoir and the Missouri.

9. Taste and odor problems attributable to increased algal densities at Yankton endured from August 27 to late October, 1953. The situation was amenable to treatment consisting of substantially higher application of activated carbon and chlorine; and, except for a few isolated periods, treated water was not unpalatable.

10. Decreased and more uniform turbidity and hardness concentrations arising from Fort Randall Reservoir development resulted in more economical water treatment at Yankton and Omaha.

11. Included in forecasts for the future are: (1) conditions conducive to taste and odor development during spring as well as in summer and fall at Yankton, South Dakota; (2) biological water quality problems at Chamberlain, South Dakota, following elevation of Fort Randall Reservoir surface to 1,340 feet, m.s.l.; (3) an eventual "initial bloom" of plankton algae following nutrient increase in Fort Randall Reservoir and subsequent water difficulties at Yankton and possibly Chamberlain; (4) probable biological water quality problems at Omaha, Nebraska, and Council Bluffs, Iowa, following impoundment of Gavins Point Reservoir; (5) similar trouble at Bismarck and Mandan, North Dakota, following anticipated Garrison impoundment in 1954; and (6) water quality difficulties at Mobridge, South Dakota, following Oahe impoundment.

12. The water quality investigation should be continued for a minimum of 2 additional years to consider effects of more extensive impoundment at Fort Randall Reservoir, Garrison, and Gavins Point impoundments, and future integrated operation.

GENERAL CONCLUSIONS AND FORECASTS

Fort Randall Reservoir

Fort Randall Reservoir effects upon Missouri River water quality were mainly related to lowered turbidity - clearer water permitting increased algal growth and thereby greater photosynthetic modification of water chemistry. From the viewpoint of water treatment, chemical and physical water quality were improved by processes related to reservoir impoundment, whereas biological quality deteriorated. However, in the economics of water treatment, benefits resulting from better physical and chemical quality have to date outweighed damages attributable to poorer biological quality. Changed water quality with respect to hardness, alkalinity, and turbidity, over the entire stretch from Fort Randall Dam to Omaha is believed to represent processes referable to reservoir impoundment. The last six months of each year (1952 and 1953) were deficient in rainfall. Fort Randall Reservoir releases, if lowered in response to greater discharges from Iowa tributaries, may have less influence upon water quality at Omaha during certain seasons.

So far impoundment has provided the clarification necessary for development of algal growths, which, assisted by sedimentation, have to date lowered hardness and alkalinity in discharged water. Volumes of water caught in the reservoir up to December 31, 1953, while great enough to afford precipitation of sediment particles, were insufficient to result in any significant leaching of minerals from previously uninundated prairie soils. Increased depths of the future will bring greater portions of the impoundment area into

contact with the washing action of circulating water, and, for a time, mineral content of reservoir water may exceed that of the river above. Increases in dissolved minerals have been noted in other impoundments in arid and semiarid regions and may not safely be discounted for Fort Randall Reservoir. Duration of this condition, once established, will depend upon reservoir operation, and general hydrologic conditions. High rates of inflow and discharge will get rid of much mineral matter. If the reservoir is maintained at the normal operation level (1,340 m.s.l.) for an extended period of time, its ability to wash minerals from soils of its bed will gradually diminish in response to sedimentation of organic materials that should eventually seal off the bottom. However, water level fluctuation will interfere with the sealing process and permit additional erosion of minerals with each successive stage elevation. If great variation in level occurs, periodic mineral increases may be expected for a number of years until supplies are depleted in superficial soil layers of the upper reservoir area. Augmentation of dissolved mineral content from soils newly covered by impounded water will result in increased water treatment costs.

Mineral increases during the early histories of reservoirs have frequently caused very dense algal growths. In some large reservoirs "initial bloom" concentrations have greatly exceeded those associated with any subsequent growths. Conditions may favor development of an initial bloom in Fort Randall Reservoir during the 1954 growing season. Its occurrence would occasion marked deterioration of biological water quality, both in and below the reservoir. Algal increases from such causes are an almost inevitable

result of water impoundment. However, rather uniform maintenance of reservoir level at a selected optimum operation point will do much to reduce the frequency, duration, and concentration of subsequent blooms.

Greater volumes of water will be stored in Fort Randall Reservoir in succeeding years. During the last 6 months of 1954, the planned operation level at 1,340 feet m.s.l. will extend reservoir headwaters above Chamberlain, South Dakota, where water level will be at the overbank stage. Clarification of upper reservoir water is expected to result in local phytoplankton densities in excess of those noted in the lower reservoir in 1953. These growths will in all likelihood occasion biological water quality problems at the Chamberlain water plant; and elimination of effects of algal concentrations may appreciably extend the capabilities of the type of treatment employed. At Dickinson, North Dakota, a water plant of similar type had extreme difficulty in operating and producing a usable water because of conditions brought about by high algal densities in Dickinson Reservoir. Advanced warning of expected difficulties, which can be provided only by a continuance of the water quality investigation, will be necessary in establishment of procedures to most successfully combat decline of finished water quality at Chamberlain.

Greater reservoir volume and depth may permit development of thermal and chemical stratification. If this condition occurs and endures until concentrations of decomposition products are built up in lower layers, phytoplankton development in the river below will be greatly stimulated by oxidation of those portions of these

compounds discharged through the dam. Thermal and chemical stratification is considered unlikely at 1,340 feet m.s.l. unless unusual meteorological conditions occur. Stratification effects would impose additional difficulties upon water treatment at Yankton.

Increases in volume of stored water at Fort Randall should also provide turbidity reduction on a year round basis, unless severe floods develop; and restrictions which high turbidity has to date placed upon algal growth in the spring and early summer will no longer be in effect in reaches below the dam. Water treatment complications occasioned by phytoplankters may therefore be expected at Yankton over greater periods of the year. Plankton densities developed in spring may exceed maximums noted to date in summer and early autumn. Water treatment at Yankton will be more difficult under conditions of increased algal concentration, and advance notice of expected water quality deterioration will be of even greater value than it proved to be in 1953.

So far nuisance levels of plankton algae have resulted mainly from diatom development. Increased densities of other algal groups, e.g. blue-greens, dinoflagellates, or certain chrysophyceaeans, could result in more severe impairment of water quality. Conditions in the Missouri River to date have favored diatoms over other groups, but dense blooms of the dinoflagellate Ceratium and the chrysophyceaeans Dinobryon and Synura, all common forms in the Missouri Basin, must, as a precautionary measure, be forecast for the future. Blue-green algae are less favored by river conditions noted to date or expected within the next year. However, possibilities for their blooms are not sufficiently remote to rule out their occurrence.

Absence of samples over an extended period (July to October, 1953) precludes estimation of maximum plankton densities attained at Omaha after Fort Randall Reservoir impoundment. No serious problems confronted water works operators; and it would appear that algal density declined somewhat in the river below Yankton. If Omaha is characterized by river turbidity levels as high as those noted during the last 6 months of 1953, plankton densities may seldom prove objectionable until impoundment of Gavins Point Reservoir. Greater reduction of turbidity would remove most present restrictions to algal growth. Nutrients provided by sewage releases at and below Sioux City make the lower reaches potentially much more productive than the river above Yankton.

Gavins Point Reservoir

This reservoir, to be completed in 1955, should remove turbid particles added to the river below Fort Randall Dam and reissue clear water at a point 75 miles downstream. Clear water will then originate 6 miles above Yankton and 88 miles above Sioux City. Phytoplankton discharged from Fort Randall Reservoir in 1953 exhibited a progressive downstream increase over the 82 miles down to Yankton. It may be assumed that plankters discharged through Gavins Point Dam will maintain or increase their density in the river over a slightly greater distance, since construction activities contributing to greater turbidity in this stretch in 1953 will then be a thing of the past. Assuming that conditions favor plankton increase for approximately 100 miles below, the plankton population will greatly benefit from nutrients contained in large volumes of organic wastes discharged at Sioux City. This stimulation is expected to result

in accelerated proliferation, thereby extending the zone of plankton growth an additional distance downstream. As a result of turbidity increase and nutrient exhaustion, plankton densities should generally decline somewhere above Omaha. However, their decline will not necessarily insure freedom from taste and odor problems at Omaha and Council Bluffs water plants. At Yankton, in 1953, taste and odor problems endured for a few weeks after plankton densities waned to a low point. Compounds contributing an unsavory flavor to water at that time originated in decay of plankton organisms, which may have been attacked by fungi of the Actinomycetes group. Deterioration of blooms between Sioux City and Omaha should be capable of producing similar unpalatable water and occasioning treatment difficulties at Omaha and Council Bluffs. Biological water quality at Yankton, already impaired by Fort Randall Reservoir, will probably average little worse after impoundment at Gavins Point.

Garrison Reservoir

Some impoundment in Garrison Reservoir occurred in fall of 1953. Greater volumes of water will be stored during spring and summer of 1954, as 3,000,000 acre-feet are to be on hand January 1, 1955. If power plant construction schedules are maintained, an additional 2,000,000 acre-feet will be stored by April 1, 1955.

Bismarck, and Mandan, North Dakota, water intakes are located about 78 river miles below Garrison Dam; and a repetition of events noted at Yankton, South Dakota, following impoundment of Fort Randall Reservoir in 1953 is expected at Bismarck and Mandan in summer and fall, 1954. Taste and odor problems should complicate water treatment for several weeks. Advance notice of imminent algal increase

to nuisance levels would be of material assistance to water operators. Phytoplankton densities at those two localities will likely exceed those noted at Yankton in 1953, since stimulation is expected from higher phosphorous and nitrogen content of river water in the Bismarck vicinity.

Planned reservoir operation foresees very infrequent surface elevations that will give pool conditions for periods of short duration at Williston, North Dakota. Biological water quality problems are not anticipated during these brief intervals of time.

Oahe Reservoir

Completion of Oahe Dam will impose a large impoundment between Garrison and Fort Randall Reservoirs. This lake will remove turbidity picked up below Garrison Dam and discharge reclarified water 111 miles upstream from Chamberlain. The silt load then entering Fort Randall Reservoir will be quite low during periods of low tributary inflow, and turbidity increase over the 111 mile stretch should not be great enough to restrict plankton growth over its greater part.

Relatively clear water over a considerable upstream distance may be considered capable of inducing biological quality difficulties at Chamberlain in the event Fort Randall Reservoir level drops below the overbank stage at that point. Clear water entering the reservoir should extend farther upstream the zone of algal growth; and algae developed in the river above may accelerate their growth in the upper reservoir. Mobridge, South Dakota, will eventually draw water from this reservoir, in which troublesome algal densities may be expected from time to time.

General

Completion of the authorized reservoir system will result in extensive limnological changes in the entire Missouri River below the mouth of the Yellowstone. The greater amount of the suspended sediment load now characterizing river flow will be retained on the floors of various reservoirs, whose combined length at nearly full stages will cover approximately 538 river miles. Distances from tailwaters to headwaters will range from less than 40 (Fort Randall to Gavins Point) to about 225 miles (Fort Peck to Garrison). Conditions at times conducive to extensive plankton algal growth should extend from the headwaters of Garrison Reservoir to below Sioux City. Periodic biological impairment of water quality may be expected in various reaches of the river all the way to Omaha-Council Bluffs. Under certain circumstances it is possible that a general bloom of one particular organism may extend over the entire system.

General chemical water quality under conditions of integrated reservoir operation may not be predicted without extensive qualification at the present time. In the long run, retention of surface runoff, photosynthesis, and sedimentation will produce lesser concentrations of minerals, as measured by hardness and alkalinity, than those prevailing at present. Initial reservoir increases in dissolved mineral content are to be expected; and their extent and duration will depend in a large measure upon reservoir operation.

Integrated reservoir operation, following establishment of different conditions in various reservoirs, may not be expected to produce any marked general uniformity of biological and chemical features over the entire affected stretch for any extensive period of time. Observation and evaluation of local situations of anticipated influence is indicated.

RECOMMENDATIONS

Investigation of central Missouri River water quality changes and relationships should be continued for at least 2 more fiscal years, and preferably until impoundment of Oahe Reservoir is substantially effected. The investigation to date has considered only the preimpoundment picture below the Yellowstone River and effects during the first 6 months of Fort Randall Reservoir with volume far below normal planned operation. Capacity for significant modification of biological quality was at hand only during late summer and fall; and knowledge of influences at other, perhaps more critical, seasons is highly desirable. Effects of greater volumes of stored water and upstream extension of the reservoir to a water treatment plant previously unaffected should be followed with care. Formation of Garrison Reservoir, now under way, is expected to cause water treatment problems at Bismarck and Mandan during the coming year. Integrated reservoir operation may result in additional modifications at Fort Randall Reservoir. Gavins Point Reservoir will extend clear water conditions an additional 75-100 miles downstream, and probably impose treatment difficulties upon the Omaha-Council Bluffs water plants.

Continuation of the study should:

a. Supply advance notifications of impending biological water quality difficulties to water operators who, previously unconcerned with algal problems, may need additional experience and training to anticipate and adequately deal with taste and odor problems. Advance warning and later assistance has been important at Yankton

and may be particularly desirable in conjunction with the water plant at Chamberlain, South Dakota.

b. Furnish information on developments attributable to clear water at all seasons in the reach from Fort Randall to Yankton, South Dakota.

c. Evaluate the situation at Chamberlain, South Dakota, as related to higher reservoir levels.

d. Provide data on influences of Garrison Reservoir, particularly with regard to water treatment at Bismarck and Mandan, North Dakota, and indicate water quality relationships of Garrison and Fort Randall Reservoirs that may be involved in future integrated reservoir operation.

e. Permit observation of conditions related to influences of algal growth in the vicinity of Omaha following impoundment at Gavins Point, and so allow more accurate forecasts of future conditions that may be expected in water supplies to larger downstream municipalities.

f. Allow estimation of Oahe Reservoir effects upon water quality and treatment at Mobridge and Chamberlain, South Dakota, and its relationships to downstream impoundments.

g. Furnish a basis of detailed information for use in forecasting general river conditions to be expected after all reservoirs are completed and operating in integration.

Future study should provide, as a minimum, sufficient sampling, analysis, and field observations to permit delineation of reservoir

effects upon general water quality. Further and more detailed investigation into causes and reasons behind reservoir induced changes is highly desirable in the interest of accurate predictions for the future.

INTRODUCTION

The central Missouri River, Williston, North Dakota, to Omaha, Nebraska, (Figure 1), supplies water to a majority of the municipalities situated on its banks. Except under conditions of ice cover, water in this river reach has been very turbid; and problems encountered in its treatment for municipal usage have been very infrequently occasioned by biological quality. A plankton reconnaissance made by the U. S. Public Health Service in 1950[1], and a study of the lower Missouri completed in 1945[2] both demonstrated a very low concentration of troublesome taste and odor producing organisms in the main stem; and led to the belief that development of such algae has been largely inhibited by excessive turbidity.

Completion of the reservoir system entailed in the Corps of Engineers Missouri River Developmental Plan is expected to substantially reduce turbidity over long river reaches. State health authorities and water works officials involved in utilization of water supplies taken from this stretch of the river have evidenced concern that future conditions of lessened turbidity may promote serious taste and odor problems arising from algal growths. The Engineering Section, Missouri Basin Health Council, comprised of the Chief Sanitary Engineers of the 10 Basin States, recommended on February 27, 1952, that the U. S. Public Health Service thoroughly investigate the matter, as the various states represented were of the opinion that they could not individually give the problem proper consideration. Accordingly, the Public Health Service outlined investigational procedures to evaluate the situation, and on March 11, 1952, notified the Division Engineer, Missouri River Division, Corps of Engineers, of the potential problem, the concern of State officials,

and actions taken to date by the Public Health Service in preparing a plan of investigation. On March 27, 1952, a detailed listing of required financial support was submitted to the Corps of Engineers. The Corps of Engineers showed immediate interest in the problem, and on May 17, 1952, agreed to provide major financial support for the study to be undertaken and directed by the Missouri Drainage Basin Office, U. S. Public Health Service.

Agreement was reached at conferences between Public Health Service and Missouri River Division, Corps of Engineers personnel that the study should permit evaluation of plankton production in the river prior to and following impoundment of Fort Randall Reservoir. It was also considered desirable at that time (June, 1952) to gain some insight into plankton productivity potential of Missouri River water under conditions of lessened turbidity that could be provided in oxbows or in abandoned settling basins. The importance of chemical and physical features in determination of types and extent of biological growths was considered in formulation of operating plans.

Plan of Operation

The plan of study agreed upon (as revised 8-11-52) was followed through June 1953, after which certain modifications were made with the approval of all cooperating agencies.

The original activity plans called for: (1) study of the main stem to determine water quality conditions prior to impoundment of Fort Randall Reservoir; (2) investigation of the Big Horn River and Boysen Reservoir to demonstrate results of clarification upon that previously very turbid stream; and, (3) evaluation of the phytoplankton productivity potential of Missouri River water by examining

clarified portions of it caught in oxbows or pumped to abandoned settling basins at the old Council Bluffs, Iowa, water plant. Impoundment in Fort Randall Reservoir began in late 1952, and by July 1953, enough water had been stored to plainly influence the river below. Emphasis was then placed upon the reservoir and its effects upon the river.

1. Main Stem.

Study of the main stem was based upon physical, chemical, and biological analysis of its water at selected points on a routine basis. Monthly analyses were planned for Williston, North Dakota, Bismarck, North Dakota, and Pierre, South Dakota; semimonthly analyses were conducted at Omaha, Nebraska; and weekly analyses were made at Chamberlain, Fort Randall Dam, and Yankton, South Dakota. After June 1953, biweekly sampling was instituted at the last three stations; monthly collections were still planned for Pierre and the two North Dakota stations; and sampling at the Omaha station was dropped until October when biological analyses only were reinstated and continued through December.

The routine analyses included turbidity, laboratory chemical, and plankton. Field chemical analyses were conducted at monthly intervals at Williston, Bismarck, Chamberlain, Fort Randall Dam, and Yankton, and semimonthly at Omaha. Laboratory chemical analyses through June 1953 consisted of total alkalinity, total hardness, calcium, magnesium, silica, nitrate, total nitrogen, total phosphorous, and, less frequently (see Table 6), fluoride, sodium, potassium, sulfate, copper, and zinc. From July to December, 1953, total hardness, total nitrogen, and total phosphorous composed the laboratory

determinations. Field analyses were: temperature, pH, monocarbonate alkalinity, bicarbonate alkalinity, available or soluble phosphorous (PO_4), ammonia nitrogen, nitrite nitrogen, and, after July 1953, oxygen. Field analyses at Yankton and Fort Randall were at biweekly intervals from August-November, 1953.

Cooperation in the main stem work was as follows:

a. Collection and chemical analysis (field and laboratory) of Williston and Bismarck, North Dakota, samples were conducted by the North Dakota Department of Health.

b. Collection of samples at Pierre, South Dakota, August 1952 - June 1953, and Fort Randall Dam, August 1952 - December 1953, and laboratory chemical analyses through June 1953, were provided by the Missouri River Division, Corps of Engineers.

c. Sample collection and field chemical analyses at Omaha were performed by the Metropolitan Utilities District of Omaha.

d. Samples were collected at Yankton and Chamberlain, South Dakota, by the respective water departments.

e. Laboratory chemical analyses, July - December 1953, for South Dakota stations, and sample collection at Pierre over the same period, were conducted by the South Dakota State Health Department.

f. All biological analyses, and field chemical analyses not listed above, were performed by the U.S.

Public Health Service.

2. Big Horn River and Boysen Dam.

Two surveys of this situation involving plankton, benthic algae, chemical, and physical features, were conducted by the U. S. Public Health Service in September 1952 and May 1953. Three series of plankton samples (February, March, and April, 1953) were collected by the Wyoming Department of Public Health.

3. Settling Basins and Oxbows.

Abandoned settling basins at Council Bluffs, Iowa, were filled with raw Missouri River water at intervals from August to December, 1952, through the cooperation of the Council Bluffs Water Department, and analyses of this impounded water were conducted after selected time lapses by the U. S. Public Health Service. The basin property was sold late in 1952 and this project, of necessity, ceased on January 20, 1953. Investigation of oxbows was initiated near Kansas City and St. Joseph, Missouri, but failure of recently filled oxbows to hold water for more than a few days resulted in an early discontinuance of this phase.

Acknowledgments

In addition to collection and analytical work listed above, the Missouri River Division, Corps of Engineers also provided operation data on Fort Peck and Fort Randall Reservoirs, transportation of samples to laboratories, drafting assistance and reproduction of figures, and miscellaneous information and assistance. Arrangements for sample collection and other assistance by water works personnel were accomplished through the cooperation of the Iowa, Nebraska, and

CENTRAL MISSOURI RIVER
GENERAL REFERENCE MAP

FIGURE 1

20-a

South Dakota State Departments of Health. Omaha daily turbidity and weekly hardness records used in Figures 4, 5, 6, and 7 were provided by the Omaha Metropolitan Utilities District. Water works personnel whose fine cooperation made routine sampling and certain analyses possible were: F. B. Jensen, Superintendent, Council Bluffs, Iowa, City Water Works; F. J. Lasell, Chemist, Omaha, Nebraska; R. N. Whiting, Water Superintendent and William Wallner, Operator, Yankton, South Dakota; and A. J. Campbell, Superintendent of Water, and Forest Seeley, Operator, Chamberlain, South Dakota. Cooperation of all agencies and individuals was excellent and their assistance is gratefully acknowledged.

Description

General features of the Missouri River region pertinent to this investigation are shown in Figure 1. The stretch Williston, North Dakota to Omaha, Nebraska, encompasses 1,012.2 river miles, receives a large number of tributaries, and begins only 36.5 river miles below the Missouri's largest tributary, the Yellowstone River. This reach of the main stem courses through plains and prairies. The stream bed is largely composed of sand, and large exposed sand bars are numerous during low water conditions. In some regions low cliffs of chalk or shale occur near the margins; and low hills or "breaks" are a common feature of the immediate surrounding terrain. Shading of water is negligible, although trees usually line the banks. The river receives untreated municipal sewage from cities and towns on its banks, and at Sioux City and Omaha acquires in addition great quantities of organic wastes from packing houses and other industries [7]. Average current velocity, considered to be rather high,

ranges from approximately 2 to 3.5 feet per second through low and medium stage discharges.

Most sampling stations (Williston and Bismarck, North Dakota; Chamberlain and Yankton, South Dakota; and Omaha, Nebraska) were located at water intakes, since economic importance of any water quality modifications would involve their occurrence at those localities. At Pierre, South Dakota, where ground water supplies the municipal requirements, sampling was from the river bridge; and at Fort Randall Dam water was taken from below the discharge tunnels. Routine samples from Fort Randall Reservoir (July - December, 1953) were from the intake towers. Sampling points in all instances were above the local sewer discharges at each of the municipalities selected for sampling; and water so obtained was expected to be free of local pollutional influences.

The main stem reservoir system will significantly alter the central Missouri River region. Locations of the various completed, incompleted, and proposed reservoirs are shown in Figure 1. Capacities, elevations, and hydrographic features of the main stem reservoirs appear in the following tables.

Table A. - Tentative Storage Allocations - Missouri River Main Stem Reservoirs

	Fort Peck (a)	Garrison (a)	Oahe (b)	Big Bend (c)	Fort Randall (a)	Gavins Point (b)	Total
Exclusive Flood Control Reserve							
Elevation (1)	2246-2250	*	1617-1620	-	1365-1375	1208-1210	
Storage (2)	960,000	0*	1,100,000	0	1,100,000	65,000	3,225,000
Annual Flood Control and Multiple - Use Capacity							
Elevation (1)	2234.7-2246	1838-1850	1610-1617	-	1350-1365	1204.5-1208	
Storage (2)	2,540,000	4,300,000	2,400,000	-	1,400,000	100,000	10,740,000
Carry-Over Multiple - Use Capacity							
Elevation (1)	2160-2234.7	1775-1838	1540-1610	-	1310-1350	1195-1204.5	
Storage (2)	11,400,000	13,800,000	14,600,000	-	2,400,000	220,000	42,420,000
Inactive Capacity							
Elevation (1)	2030-2160	1673-1775	1415-1540	-	1230-1310	1160-1195	
Storage (2)	4,500,000	4,900,000	5,500,000	340,000	1,400,000	155,000	16,795,000
Total Capacity Acre-feet	19,400,000	23,000,000*	23,600,000	340,000	6,300,000	540,000	73,180,000

(1) Feet above mean sea level
(2) Acre-feet

* Exclusive of 1,500,000 acre-feet of flood control storage between elevations 1850 and 1854 for extreme floods.
(a) Reservoir now in complete or partial operation.
(b) Reservoir under construction.
(c) Proposed reservoir.

Table B. - Hydrographic Features of Main Stem Reservoirs

	Fort Peck	Garrison	Oahe	Big Bend	Fort Randall	Gavins Point
Average Pool Elevation	2,230	1,829	1,603	1,410	1,348	1,207
Depth at Dam in feet						
Maximum	220	185	205	65	145	50
Average	200	164	188	65	118	47
Reservoir Length in River Miles						
Maximum	190	235	259	75	159	50
Average	180	218	244	75	128	48
Shoreline in Miles						
Maximum	1,600	1,600	2,350	120	-	100
Average	-	-	-	120	550	-
Area in Acres						
Maximum	245,000	390,000	376,000	19,800	118,400	33,000
Average	217,000	326,000	311,000	19,800	79,000	30,400

PRESENTATION OF DATA

Climatological Conditions

Land areas contributing the major part of runoff to the central Missouri River are contained within the states of Wyoming, Montana, North Dakota, South Dakota, Nebraska, and Iowa (Figure 1). The 1952 Weather Bureau Annual Summaries of climatological data for those states indicate that weather in each was drier and in most warmer than normal. Annual 1952 average temperatures, precipitation, and departures from the normal were:

	Average Temp. °F	Departure from normal	Inches Average Precip.	Departure from normal
Wyoming	42.6	+ 0.6	11.12	- 3.19
Montana	42.8	- 0.4	10.62	- 3.81
North Dakota	41.3	+ 1.3	12.25	- 4.87
South Dakota	45.9	+ 0.4	14.03	- 5.16
Nebraska	50.3	+ 0.8	20.34	- 1.92
Iowa	49.1	+ 0.5	29.8	- 1.57

The outstanding climatological event of the year, despite deficient precipitation, was major flooding of the Missouri and most tributaries in March and April. The Weather Bureau attributed flood conditions to rapid thaw of snow and a layer of ice or frozen ground beneath the snow cover. This frozen layer slowed infiltration during a period of rapid thaw in March and allowed most snow runoff to reach the rivers. Flood conditions extended from the Milk River in Montana to the mouth of the Missouri. Several towns were partly or wholly inundated. Flooding of Omaha was barely

prevented by last minute elevation of the floodwall with boards and sandbags.

Precipitation in Montana was only 0.83 inches greater than the driest year on record. The period September 1 - December 31 was the driest in the climatological history of the State of North Dakota. Decreasing amounts of precipitation as the year progressed characterized the weather of a major portion of the area contributing runoff to this river reach.

In 1953 all states had temperatures warmer than normal, and Montana and the Dakotas were wetter than usual. Deficient precipitation characterized Wyoming, Nebraska and Iowa. All months were above normal in temperature except April, May, June, and July in Montana and North Dakota; April, May, and July in Iowa and South Dakota; and April and May in Wyoming and Nebraska. These exceptional months were all colder than normal. June was the wettest month in all states except Wyoming and Montana, where greatest precipitation occurred in May. Precipitation was generally below normal during the last 6 months of 1953. Climatological averages and departures from normal in 1953 were as follows:

	Average Temp. °F	Departure from normal	Inches Average Precip.	Departure from normal
Wyoming	44.5	∱ 2.5	11.79	- 2.43
Montana	45.3	∱ 2.1	16.85	∱ 1.72
North Dakota	42.7	∱ 2.8	20.04	∱ 2.92
South Dakota	47.3	∱ 1.9	21.84	∱ 2.65
Nebraska	51.8	∱ 0.7	20.43	- 1.73
Iowa	50.4	∱ 1.3	25.87	- 5.50

Physical Features

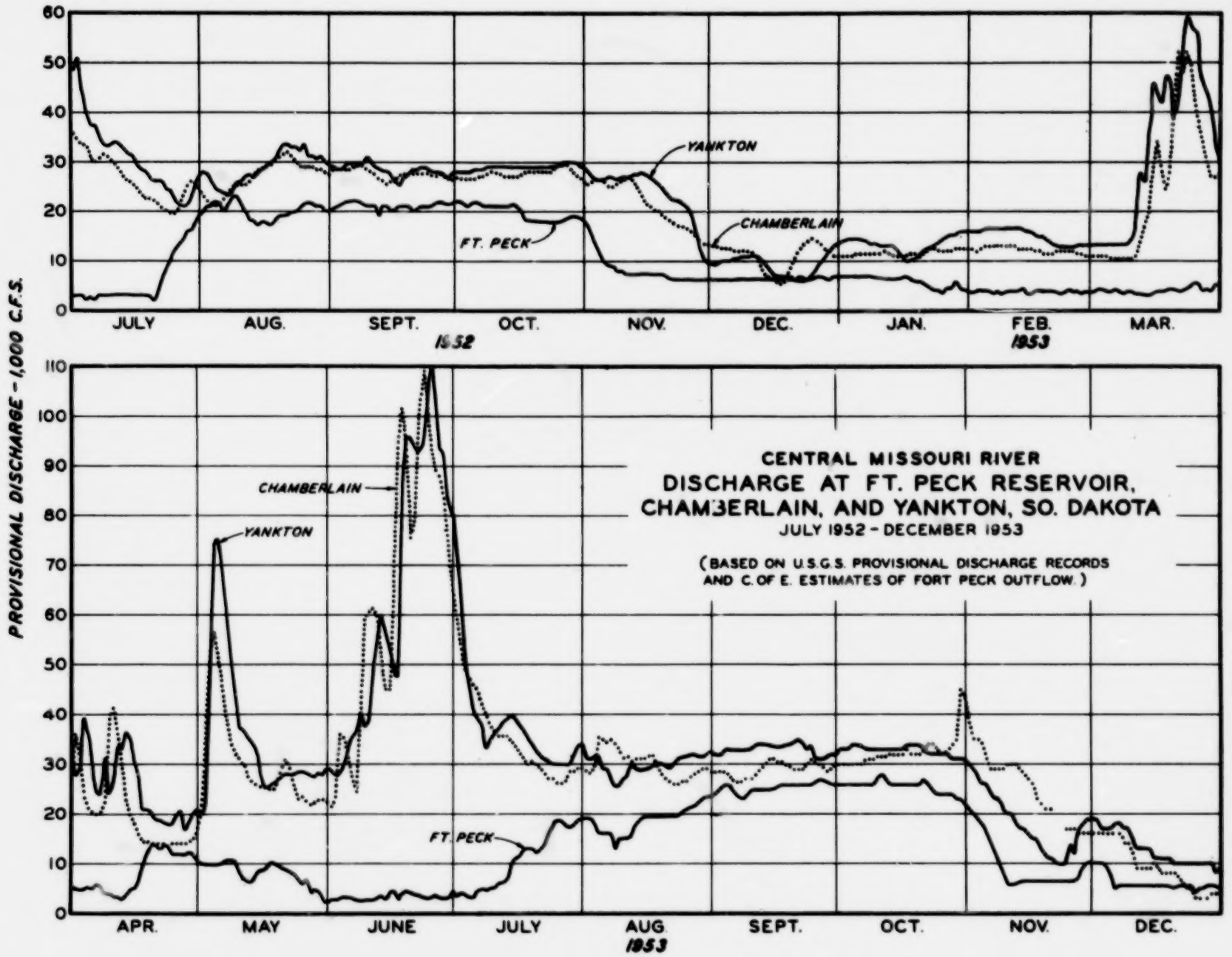
Methods and Sources of Information

Discharges were obtained from provisional U. S. Geological Survey discharge records. Reservoir operation data was supplied by the Corps of Engineers. Turbidity was measured with Jackson type turbidimeters, the lowest range of which is 25 ppm. Daily turbidity records at Omaha were supplied by the Metropolitan Utilities District.

Discharge

Discharge patterns at the 5 more routine stations were quite similar over the 17 month period (Figures 5 and 7). Rather uniform discharges in the vicinity of 30,000 c.f.s. endured from late July until late November of each year. Low stages, down to below 5,000 c.f.s. upon occasion, but usually in the neighborhood of 10,000 c.f.s., occurred during the period December 1952, to early March 1953, and were again evident in November and December, 1953. Drops to 5,000 c.f.s. or less during early low flow periods are assumed to represent interferences by ice formation. High river stages occurred in March, April, May, and June. Early spring rises in the Missouri River are mainly occasioned by snow melt over the plains section of the basin; later stage elevations, particularly the June rise, come from rainfall over the plains coupled with snow melt in the mountains. The coincidence in time of high stages at all five stations indicated a basin-wide nature of conditions producing increased runoff.

Releases from Fort Peck Reservoir had a general influence upon


PROVISIONAL DISCHARGE - 1,000 C.F.S.
60
50
40
30
20
10
0
YANKTON
CHAMBERLAIN
FT. PECK
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
1952
1953
110
100
90
80
70
60
50
40
30
20
10
0
CHAMBERLAIN
YANKTON
FT. PECK
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
1953
CENTRAL MISSOURI RIVER
DISCHARGE AT FT. PECK RESERVOIR,
CHAMBERLAIN, AND YANKTON, SO. DAKOTA
JULY 1952 - DECEMBER 1953
(BASED ON U.S.G.S. PROVISIONAL DISCHARGE RECORDS
AND C. OF E. ESTIMATES OF FORT PECK OUTFLOW.)

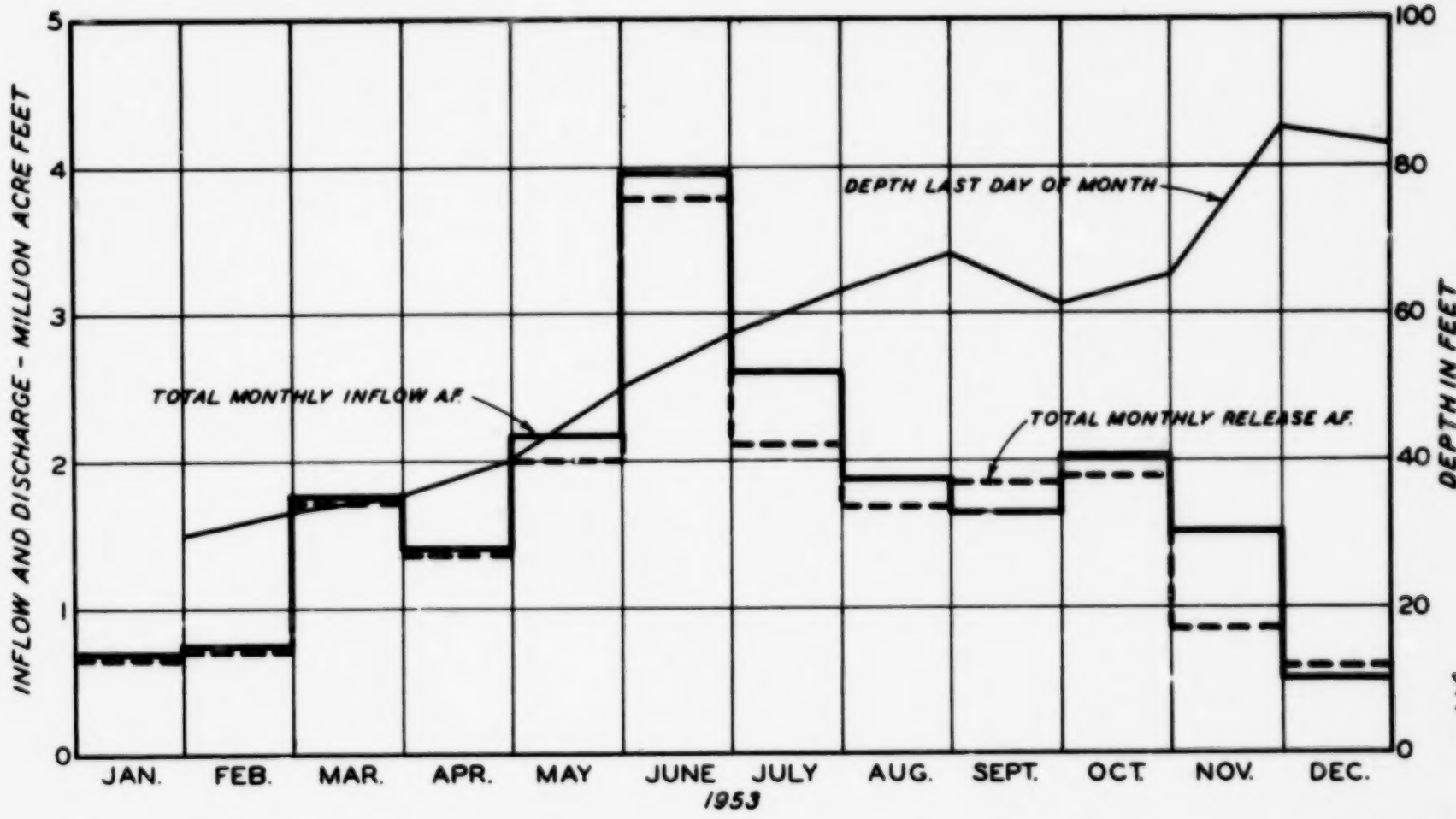
37-a

FIGURE 2

flow each year; and Fort Randall Reservoir regulation was evident in discharges at Yankton in the fall of 1953. Discharges from Fort Peck Reservoir are compared with those at Chamberlain and Yankton in Figure 2. Approximately 13 and 15 days, respectively, are required for passage from Fort Peck to Chamberlain and Yankton when discharge ranges 25-30,000 second feet. During the 3-1/2 month periods (August to November) of uniform discharges in the middle ranges, Fort Peck releases ranged from 70 to almost 90% of discharges at Chamberlain and Yankton. Some loss of Fort Peck water undoubtedly occurred in passage, but it is evident that the greater volume of water past downstream stations during these periods originated in Fort Peck Reservoir. Cutdown of Fort Peck releases at the end of October was followed, at appropriate time intervals, by rather sharply decreased discharges at Chamberlain each year and at Yankton in 1952. In 1953, stream flow at Yankton could be affected by regulation at Fort Randall Dam, where cutdown occurred at the end of October. Operation of Fort Randall Dam (Figure 3) during 1953 resulted in a gradual reservoir build-up, although, in general, volume of inflow only slightly exceeded releases, and in September and December fell below the amounts discharged. Capacity for significant downstream regulation was on hand following recession of the June rise. However, reservoir formation was at the expense of discharges over an extended period of time and no marked retention of any seasonal runoff occurred.

Turbidity

Despite its muddy appearance, the Missouri River does not carry a particularly heavy suspended sediment load in terms of dry



CENTRAL MISSOURI RIVER
FORT RANDALL RESERVOIR
1953 OPERATION

28.a

FIGURE 3

weight per volume. Maximum percentages observed during the period 1937-1948 were: Williston, North Dakota, 2.19; Bismarck, North Dakota, 1.28; Pierre, South Dakota, 1.71; Yankton, South Dakota, 2.52; and, Omaha, Nebraska, 3.37[3]. The usual load was less than 1 percent. However, turbidity (suspended sediment interference with light penetration) is very high. This apparently anomalous situation is due to the presence of small, light, flattened clay particles whose effectiveness in reflecting light is very great, and yet whose weight amounts to a rather small overall sediment load.

At stations upstream from Fort Randall Reservoir, and at all stations before significant regulation was provided by water stored in this reservoir, turbidity relationships were practically identical (Figure 7, Tables 6a - g.). Turbidity was lowest during winter ice cover and greatest during periods of high discharge in spring and early summer. Long periods of rather uniform discharge, roughly from July to November, were characterized by rather uniform turbidity near the middle ranges. Prior to reservoir impoundment turbidity was consistently greatest at Omaha.

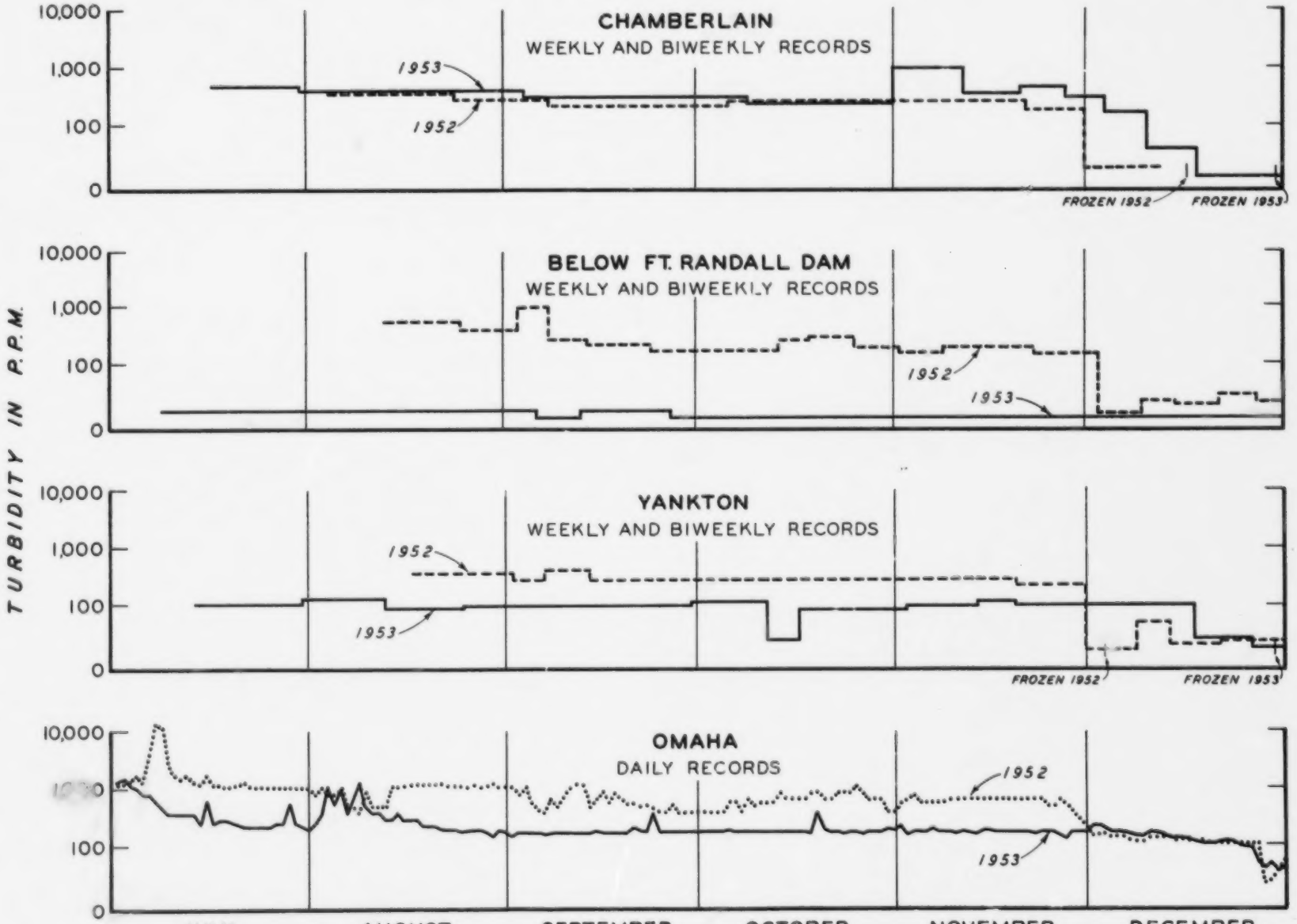
Associations of turbidity extremes with ice cover and high discharges suggest that surface runoff plays the major role in transport of turbid water to the river. Surface runoff is practically nonexistent during periods of ice cover and is largely responsible for high stages in open water seasons. Bank erosion along the main stem and major tributaries, an action most common during high stages and negligible under ice cover, apparently has a significant part in turbidity contributions. Bed scour appears to be unimportant in the overall turbidity picture, as bottom sediment particles contain very

little clay and offer but slight resistance to light penetration when temporarily brought into suspension.

Fort Randall Reservoir effects upon turbidity are striking when records for the last 5 months of 1952 are compared with those for the last half of 1953 (Figure 4); turbidity reduction by the reservoir was not especially significant until May 1953. At levels maintained during the last 6 months in 1953 Chamberlain was the first station upstream from reservoir influences. There 1953 turbidities were generally in excess of those occurring during the same months in 1952. At all stations below Fort Randall Dam, 1953 turbidities were markedly lower, and, with the exception of Yankton, more uniform than those observed in 1952. Irregularities and a large amount of the increase at Yankton in 1953 were attributed to dredging operations at Gavins Point damsite. Investigation in August and September 1953, showed that only 17 percent of the increase between Fort Randall and Yankton (a distance of 82 river miles) was attained at a point 41 miles below Fort Randall Dam and 4 miles below the mouth of the Niobrara River, and it seems unlikely that 4.8 times as much would be supplied by another 41 mile stretch under normal conditions.

Temperature

Water temperature attained its maximum in August and July, and minimums occurred during the period December-March (Table 1). Not much variation was evident among various stations during any one month. Surface temperatures in Ft. Randall Reservoir prior to ice cover in 1953 were never observed to vary from those of discharged water on the same date. Vertical temperature measurements made in



CENTRAL MISSOURI RIVER

TURBIDITY COMPARISONS

JULY - DECEMBER, 1952 AND 1953

30-a

FIGURE 4

the lower end of the reservoir in August and September 1953, showed uniform temperature from surface to bottom.

Temperature influences upon plankton algae are indirect. Temperature affects bacterial activities that break down complex compounds to furnish such elements as nitrogen and phosphorous in forms available for algal use; there is a decided drop in such processes at the onset of cold weather.

Ice Formation

Dates of appearance and disappearance of permanent ice cover at each station were taken from U. S. Geological Survey daily discharge records. The dates are assumed representative of only the immediate area of each gaging station, but they offer more accurate information on the river in general than do weekly or monthly observations of sample collectors.

	Dates Frozen	Dates Ice Out
Pierre	11-29-52	3-21-53
	12-30-53 (Possibly mostly frozen Dec. 25)	-
Chamberlain	12-16-52	3-16-53
	12-30-53 (Possibly mostly frozen Dec. 25)	-
Below Fort Randall Dam	12-5-52	12-17-52
	1-7-53	3-13-53
	Not frozen prior to December 31, 1953	
Yankton	11-29-52	3-12-53
	12-30-53 (Possibly mostly frozen Dec. 25)	-
Omaha	Not reported frozen 1952 or 1953	

Ice cover below Fort R ndall Dam was broken on December 17, 1952, and on the following day, 25 miles below were reported open. The next ice cover persisted until the general break-up. The first appearance of ice cover was marked by sharp drops in turbidity and discharge (Figure 7) in 1952. In 1953 hese decreases occurred about 5 days before reported freezing at gaging stations. Omaha was not reported frozen, although at times the river there contained large quantities of floating ice.

Chemical Features

Methods and Sources of Information

Analyses were performed according to procedures listed in Standard Methods for the Examination of Water and Sewage, Ninth edition, 1946, American Public Health Association. The Missouri River Division Laboratory, Corps of Engineers, due to preoccupation with defense work, was unable to perform analyses during the first 4½ months of 1953. Variability induced by the resultant prolonged storage period was considered too great to permit alkalinity, total nitrogen, and nitrate records to represent river conditions at times of collection. These nitrogen analyses for the period January-June, 1953, are not included, and the only alkalinity data used are those obtained from field analyses. Weekly hardness records at Omaha used in Figures 5 and 6 were available through the courtesy of the Omaha Metropolitan Utilities District. These records do not appear in tabular form in this report, but are available, covering a period of years, at the Metropolitan Utilities District Office, and at the Omaha water plant.

Alkalinity and Hydrogen Ion (pH) Relationships

Measurements of alkalinity and hydrogen ion concentration offer considerable insight into the nature and extent of biological processes operative in natural bodies of water. In the Missouri River, and in most natural waters of fair mineral content, pH and alkalinity are determined by relative amounts of carbon dioxide, bicarbonate, and monocarbonate. The presence of monocarbonate is indicated by pH values exceeding 8.0; bicarbonate alone gives a pH of 8.0; and

bicarbonate in conjunction with free carbon dioxide (carbonic acid) results in pH values below 8.0.

Carbon dioxide, produced by organic decomposition and respiration, will react with monocarbonate to form bicarbonate and water. Photosynthesis by aquatic plants utilizes carbon dioxide, which is generally removed from bicarbonate. This process produces monocarbonate and water. Decomposition therefore reduces pH and monocarbonate and increases bicarbonate, while the reverse is true for photosynthesis. The extent and rate of decomposition is largely determined by quantities of decomposable organic matter and water temperature. Photosynthesis is mainly dependent upon availability of inorganic plant nutrients and light. However, some nutrient elements originate in decomposition, and in many instances the slow down of decomposition occasioned by lower water temperature is accompanied by a decreased photosynthetic rate. In some cases the main hindrance to photosynthesis in winter is exclusion of light by ice and snow cover.

Hydrogen Ion Concentration

Hydrogen ion (pH) measurements made at monthly and semimonthly intervals may not be considered indicative of the exact degree of variation that occurred at each station. The usual pH value of the Missouri River at discharges in middle and low ranges, and when decomposition and photosynthetic influences are largely inoperative, appears to range from 8.1 to 8.3 (Figure 5, Table 1). In view of other chemical features, this pH level demonstrates the normal presence of a soluble form of monocarbonate (Na_2CO_3 or K_2CO_3). Maintenance of pH at this level over long periods of time, including ice

cover conditions, indicated a rather low level of organic decomposition at most stations. Variation in hydrogen ion concentration was occasioned by high discharges, whose dilution reduced pH below 8.0, and photosynthesis, which elevated pH upon occasion to 8.5. Measurements of pH did not always coincide with high flows, but values obtained during high stages were uniformly lower. With regard to photosynthesis, it may be noted that highest pH values occurred below Fort Randall Dam and at Yankton when plankton densities reached their maximum in early fall, 1953. Such relationships of pH to discharge and photosynthesis characterize many streams(4). Photosynthetic alteration of pH was also evident at Yankton, Omaha, and below Fort Randall Dam in May, 1953.

At Williston and Bismarck higher temperatures during open water seasons were usually associated with pH values below 8.0, but they rose to 8.1 and 8.2 when water temperature declined to near 0°C. These relationships of pH to temperature indicate decomposition influences and suggest quantities of organic matter greater than those at other stations.

Alkalinity

Monocarbonate (CO_3)

The Missouri River, as a result of the relatively unwashed nature of many soils in its drainage basin, normally contains small amounts of sodium or potassium monocarbonate that originate in alkali formations. Alkalinity assumed due to this soluble monocarbonate varied from about 0.1 to 6.0 ppm., and its presence gave fairly constant pH values in the range 8.1 - 8.3, when water chemistry was not significantly influenced by organic decomposition, photosynthesis,

or great dilution from surface runoff. In areas of greater rainfall, e.g. the Ohio Basin, the presence of monocarbonate in streams is practically always indicative of photosynthesis, as only calcium and magnesium bicarbonate usually result from flow through the well washed soils of such regions. In the Missouri, monocarbonate-photosynthesis relationships are not as finely drawn; and normal variation at stations where algal growths were not especially great indicates that photosynthetic influences, although they may be involved in lower concentrations, are not safely measurable unless monocarbonate exceeds 6.0.

At Bismarck and Williston the usual absence of monocarbonate during open water seasons apparently represented its elimination by CO_2 arising from organic decomposition and not its absence in the drainage system above these points. As indicated by pH values monocarbonate was present when cold weather curbed organic decay (Table 1).

Omaha is situated below the entrance of considerable untreated organic pollution from municipalities and packing houses (Sioux City, Iowa; Blair, Nebraska; etc.) and there monocarbonate disappeared after the onset of cold water conditions. Influences of organic wastes have been noted to extend farther down streams when cold weather slows bacterial action, and this phenomenon at Omaha may not be considered unusual. Lower pH levels and loss of monocarbonate noted at Omaha in spring and summer of 1953 were assumed due to dilution with surface runoff, as high stages usually coincided with times of sampling. Absence of monocarbonate was also noted during the June rise at Chamberlain. At other stations the sampling schedule missed

the highest discharges.

In most instances monocarbonate levels in excess of 6.0 (usually associated with pH of 8.3 or greater) were occasioned by algal photosynthesis. Photosynthetic effects were most striking in the region of clear water below Fort Randall Dam following recession of the June rise in 1953 (Table 1). General association of these monocarbonate elevations with increased algal density may be noted by reference to Figure 7 and Tables 9e and 9f. Note also that decline in phytoplankton volume was accompanied by decreased monocarbonate alkalinity. At Omaha monocarbonate rises that occurred in September, November, and December, 1952, were in general coincident with plankton increases (Figure 7, Table 9g).

Bicarbonate (HCO_3)

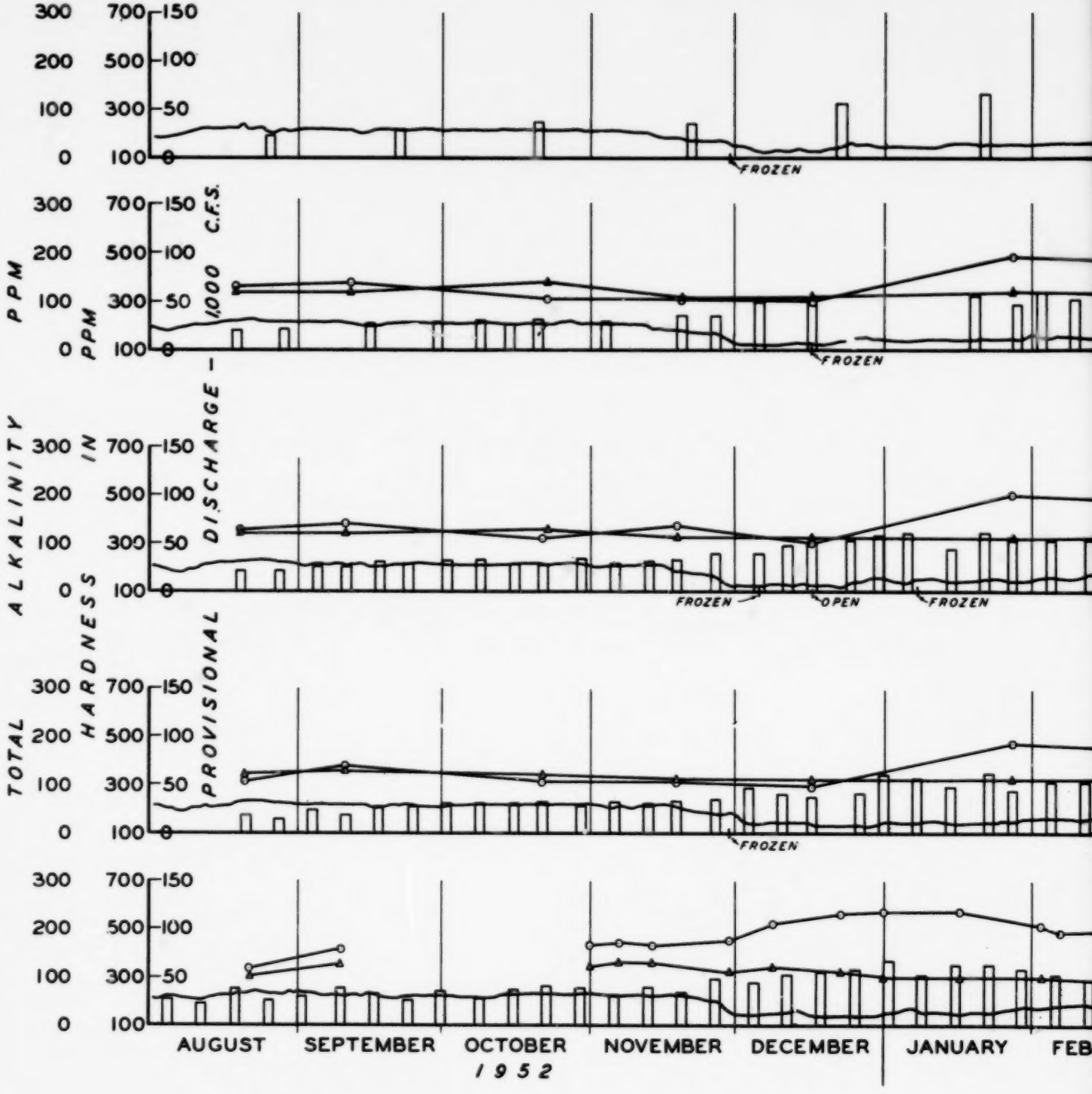
Bicarbonate originates in flow of water through and over the earth, and usually is produced by the action of carbonic acid upon limestone. In more humid regions it is normally the only form of carbonate entering streams, where monocarbonate produced by photosynthesis is at its expense. In the Missouri River a soluble monocarbonate also enters, and possibilities exist for a slight augmentation of bicarbonate in this stream by the action of CO_2 produced by decomposition. However, quantities of HCO_3 so evolved would amount at most to only 6 - 10 ppm.; and total alkalinity is almost entirely dependent upon amounts of HCO_3 originating in soil drainage.

HCO_3 (and thereby total alkalinity) tends to vary inversely with rate of flow since low discharges contain greater percentages of ground water. This relationship to discharge is more characteristic of small streams, but it was generally evident in the Missouri,

although altered by reservoir regulation (Figure 5). Average concentrations of HCO_3 tend to become greater with downstream distance because of increased entrance of ground water during low flow periods. This pattern was true of the Central Missouri River when the entire stretch from Williston to Omaha is considered, but there was considerable variation among some of the intermediate stations (Table 1). Circumstances did not permit sampling of all tributaries, but it appears that their inflows, either more or less alkaline than the main stem, were mainly involved in this intermediate variation. The 1952 average at Bismarck exceeded that at Chamberlain, while at Fort Randall Dam, the mean was greater than at Chamberlain and Yankton (Table 2). Inflow of the Niobrara River tended to dilute alkalinity. During the 5 month period (August-December 1952) its average alkalinity was 112 ppm. and its discharge amounted to approximately 6 percent of that in the Missouri at Yankton. Alkalinity decreased from 163 ppm. at Fort Randall to 154 ppm. at Yankton. The Niobrara inflow alone would have reduced mean alkalinity to 159 ppm.

Alkalinity over the entire reach covered by this study was noticeably influenced by Fort Peck Reservoir discharges during the period August to November when such reservoir releases accounted for the greater volume of discharge (Figures 2 and 5). During 1953 Fort Randall Reservoir augmented effects of Fort Peck releases.

For the period August 1952 - July 1953, total alkalinity curves at Chamberlain, Fort Randall, and Yankton (Figure 5) are quite similar, remaining rather uniform throughout the period of high releases from Fort Peck, dropping somewhat at onset of ice cover, rising during the winter period of low discharge, and then falling again in response to general high water conditions extending through the


TOTAL HARDNESS IN PPM
ALKALINITY IN PPM
DISCHARGE - 1,000 C.F.S.
PROVISIONAL
300
200
100
0
700
500
300
100
150
100
50
FROZEN
FROZEN
FROZEN
OPEN
FROZEN
FROZEN
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEB
1952
HARDNESS
DISCHARGE
ALKALINITY
pH

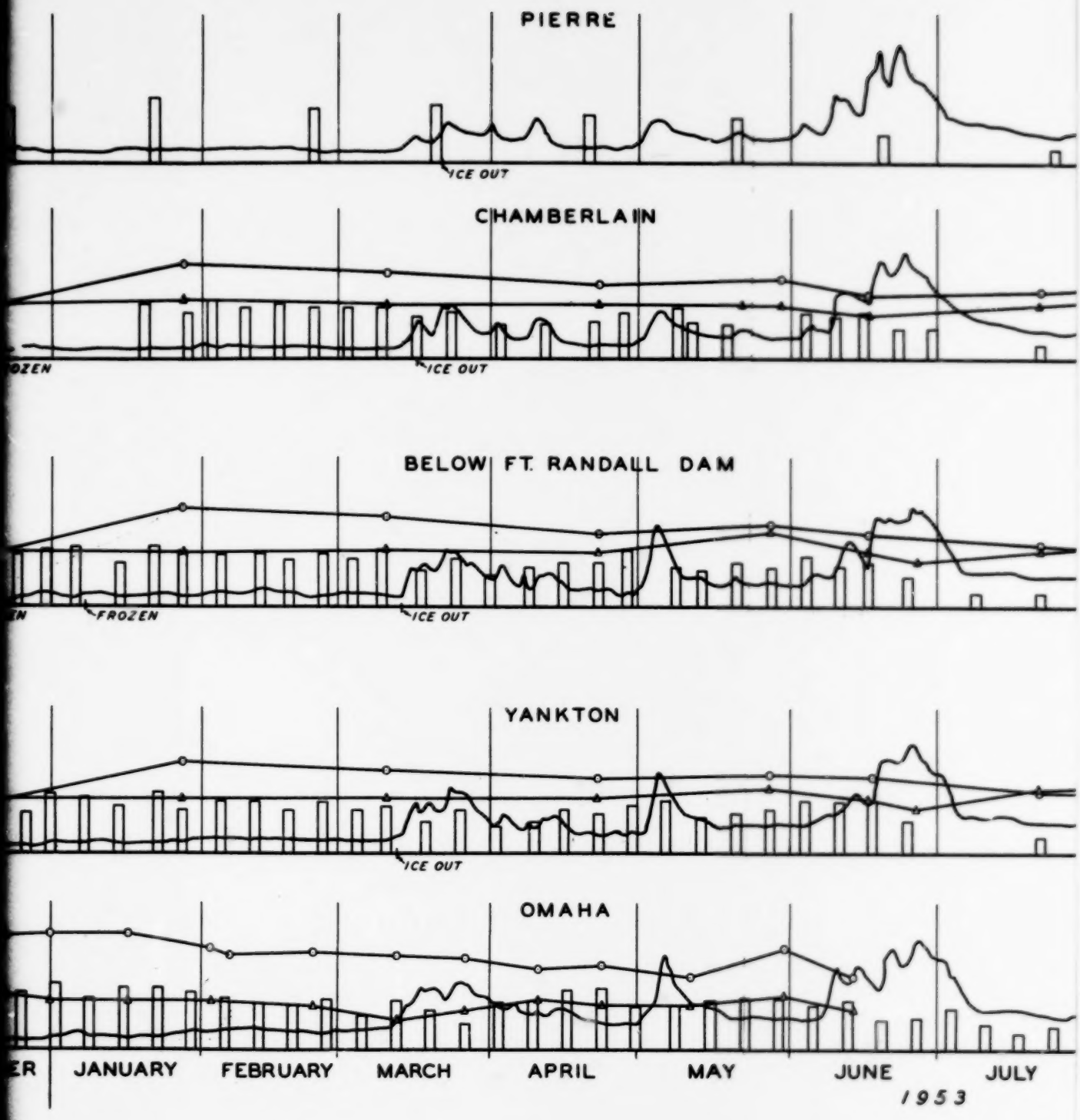
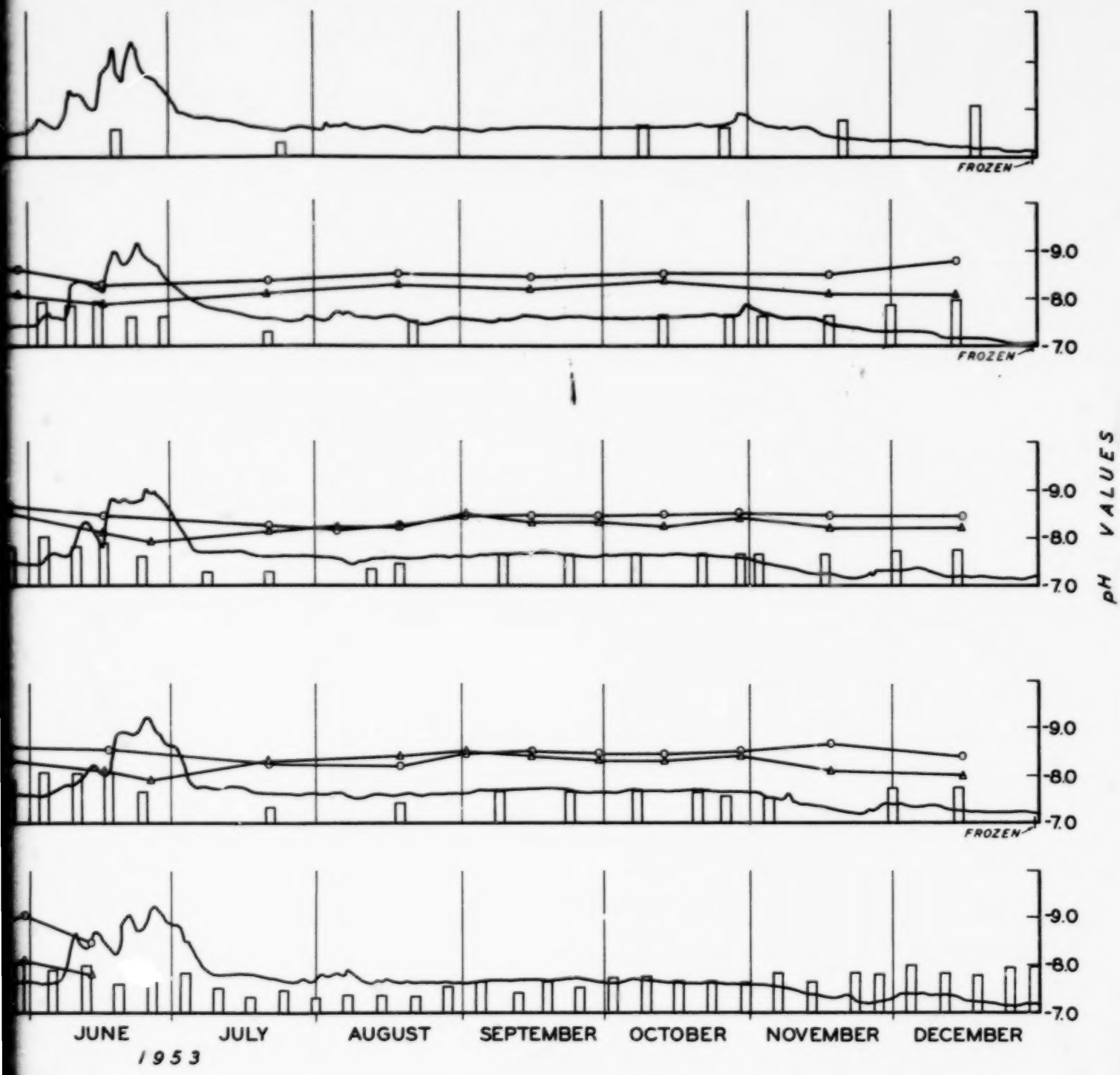

PIERRE
ICE OUT
CHAMBERLAIN
ICE OUT
BELOW FT. RANDALL DAM
FROZEN
ICE OUT
YANKTON
ICE OUT
OMAHA
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
1953

FIGURE 5



CENTRAL MISSOURI RIVER

HARDNESS, ALKALINITY, pH AND DISCHARGE

AUGUST 1952–DECEMBER 1953

June rise. Lowest alkalinities were recorded during and shortly after the period of high releases from Fort Peck Reservoir; and it should be noted that most alkalinities measured at low stages between spring and summer high water periods were noticeably higher. It seems reasonable to assume that lowest alkalinity occurred during the June rise. At Omaha, sampling was coincident with high stages in March and June, 1953. During the March high stage, alkalinity was in excess of that measured during the period August - November, 1952, while in June it was lower. Inasmuch as lowered alkalinity resulting from high stages would necessarily be of relatively short duration, Fort Peck releases must be credited with the greatest reduction in alkalinity concentration over this extended period.

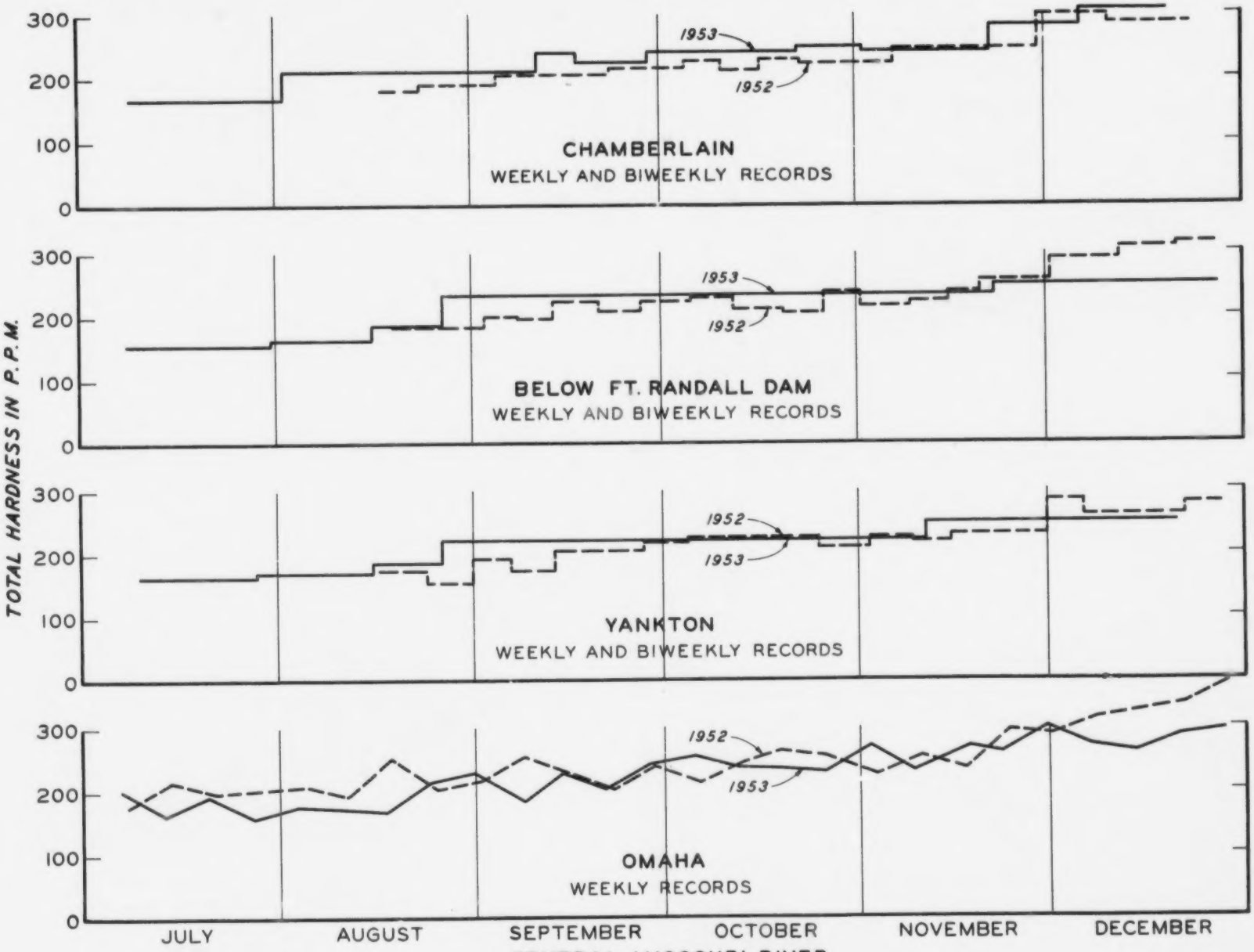
Following the 1953 June rise, and during the later period of increased releases from Fort Peck Reservoir, alkalinity concentration at Chamberlain was higher than that noted during 1952; but an increase following cutdown of Fort Peck releases was again evident. The picture below Fort Randall Dam and at Yankton was essentially one of uniformity in the range of 140 - 150 ppm. from September to December, 1953, with a variation of 110 - 120 ppm. in July and August. Reduced uniform alkalinities at those two stations are attributable to influences of storage above Fort Randall Dam. Accumulation of water in this reservoir was at the expense of discharges over the entire period, and no build-up of any seasonal runoff occurred (Figure 3). It may be noted in Table 2 that alkalinity below Fort Randall Reservoir averaged 17 ppm. below that recorded at Chamberlain. This latter station may be assumed representative of the major inflow into the reservoir and reduction of alkalinity within the reservoir is attributable to factors other than dilution by retained surface runoff.

When cognizance is given the fact that in 1952 Fort Randall alkalinity averaged somewhat greater than that at Chamberlain, reduction may actually have been greater than that evident in measurements at the two stations. Some credit for alkalinity decrease in the reservoir may be accorded sedimentation, but photosynthesis by plankton algae, with production of relatively insoluble calcium and magnesium monocarbonate, was apparently more concerned. The slight increase in average alkalinity between Fort Randall and Yankton was not in keeping with conditions observed in 1952, and did not represent a significant change in discharge or alkalinity of the Niobrara River. Hydraulic dredging at Gavins Point damsite, which was observed to impart a grayish turbidity to the river at Yankton, was apparently responsible for this slightly greater average. Alkalinity at Yankton was not consistently higher (Table 1) and was sometimes lower.

Hardness

Hardness depends upon the presence of calcium, magnesium, iron, and manganese. It is most commonly due to calcium and magnesium, which are usually in combination with carbonate and bicarbonate ions; and there is frequently a general correlation between hardness and alkalinity. When quantities of calcium or magnesium sulfate are present, hardness and alkalinity may differ widely.

The hardness picture in the Central Missouri River (Figure 5) presented many similarities to alkalinity variations over the 17 month period - lowest concentrations were related to high discharges and reservoir releases, and maximums occurred during periods of low annual discharge. During the last 4 months of 1953 hardness was generally greater than during the same period in 1952. Lowest hardness



CENTRAL MISSOURI RIVER

HARDNESS COMPARISONS

JULY - DECEMBER, 1952 AND 1953

FIGURE 6

40-a

occurred at all stations following recession of the June rise in early July, 1953. Factors associated with minimums at that time are rather difficult to discern on the basis of available data. The river was not then influenced by high Fort Peck releases, and apparently the only permissible assumption at this time is that the preceding period of high runoff washed the soils sufficiently to remove temporarily carbon dioxide and thereby make less erosive the ground water, inflow of which maintained middle stages for a short period before increased Fort Peck releases were required. Lowered hardness during this period was accompanied by an alkalinity decline - a fact lending support to the above assumption.

Comparison of 1952 and 1953 levels (last 6 months, Figure 6) shows that hardness was greater in water above Fort Randall Reservoir in 1953. However, it averaged considerably less below Fort Randall Dam all the way down to Omaha (Table 2). This hardness decrease at the lower stations, like the alkalinity decline, reflects the influences of sedimentation and resultant increased photosynthesis in the clear reservoir and river below. Hardness at stations below the reservoir was not consistently lower in 1953 but was much more uniform, a feature of considerable importance in water treatment.

Oxygen

Oxygen analyses were not initiated until August, 1953. At that time it was deemed desirable, in view of the unrelated occurrence of monocarbonate, to apply still another measure to evaluate photosynthetic intensity. Photosynthesis, which consists essentially of combining hydrogen ions from water with CO_2, releases oxygen from water as a byproduct. In experimental studies of

photosynthesis, quantities of oxygen so evolved are utilized as a measure of photosynthetic rate or intensity. In natural bodies of water oxygen can be used as an indication of photosynthetic rate only when quantities in solution result in supersaturation for the temperature and altitude, since values up to 100 percent saturation may possibly result from absorption from the atmosphere.

A summary of oxygen analyses results appears in Table 3. Saturated or nearly saturated conditions were found at Chamberlain only after the onset of cold weather. Below Fort Randall Dam, and in Fort Randall Reservoir, a supersaturated condition was the general rule, and supersaturation was evident at Yankton, with only one exception, until the middle of October. Oxygen is produced by photosynthesis during daylight hours only and some decline is normal at night when aquatic plants change roles from producers to consumers. Measurements at Yankton were always conducted in early morning -- while those at Fort Randall and Chamberlain were made in early and late afternoon, respectively. Therefore, on a daily basis, it appears reasonable to assume that Yankton oxygen concentration could have closely approached or exceeded that at Fort Randall if hours of measurement had coincided. In late October, November, and December, oxygen content below Fort Randall Dam was influenced by algal growths on walls and bottom in the same area and was not characteristic of the plankton algal population. During these months oxygen below the dam exceeded that in the reservoir, which was also supersaturated. Oxygen levels showed no photosynthetic effects at Chamberlain, but marked effects were evident at Fort Randall and Yankton.

Nitrogen Cycle

Due to the prolonged storage of samples, organic and nitrate nitrogen records for stations below Bismarck covering the period January to June, 1953, were judged too variable for inclusion. Other nitrogen data are considered accurate.

Ammonia Nitrogen

Ammonia nitrogen (Table 4a) was present in greatest concentration during the period September 1952 - January 1953. It was never noted at Williston; and levels occurring at Bismarck were usually considerably lower than those farther downstream. Ammonia dropped to zero at times at all stations tested during summer of 1953 and, during fall of that year, did not attain more than a fraction of the levels reached in 1952. Greater amounts in 1952 possibly may be assigned to prolonged influences of the major flood experienced that spring. In general, impoundment in Fort Randall Reservoir had no influence upon ammonia nitrogen.

Nitrite Nitrogen

Nitrite was found only at Williston, Bismarck, and Omaha (Table 4b). Nitrite in general has only a transitory role in nitrogen cycle relationships and its constant presence is frequently indicative of local sewage contamination. Nitrite may also be present when large numbers of zooplankters (particularly the microcrustacea) furnish a constant supply of animal waste products. However, no such zooplankter concentrations occurred at any of the three stations exhibiting nitrite, and its presence is assumed indicative of increased organic matter. At Omaha a sewer outfall is situated 100 feet below the water plant intake.

Nitrate Nitrogen

High nitrate levels recorded at Williston and Bismarck, like alkalinity and pH relationships, suggest greater quantities of decomposable organic matter (Table 4c). Concentrations at Omaha were generally in excess of those noted in the stretch from Pierre to Yankton, presumably the result of entry of wastes at Sioux City and Blair. Nitrate exhibited but little increase in the stretch from Pierre to Yankton. High concentrations of nitrate such as those recorded at Bismarck have not been observed to endure over any great stream distance or period of time.

Organic Nitrogen

This analysis was not conducted on North Dakota samples. Variation noted at and among the other stations (Table 4d) was not particularly significant, although in general maximum concentrations were recorded during the summer and fall of 1953 when ammonia nitrogen was at its minimum.

Significance of Nitrogen Analyses

Nitrogen is an essential element for growth and photosynthesis of algae. Some algae, notably certain blue-greens, have the ability to fix free nitrogen gas dissolved in water and are more or less independent of available nitrogen compounds. However, the majority of the algae noted to date in the Missouri River are dependent upon nitrogen compounds for their recourse to this essential element. Many of these algae are able to use either ammonia or nitrate nitrogen. Organic nitrogen-nitrogen in living or dead bodies or in organic compounds - is not available for use. It, however, serves as an approximate guide to the extent of nitrogen usage and general supply, since

it is ultimately converted into available nitrogen ($NH_3 \rightarrow NO_2 \rightarrow NO_3$) by bacterial action.

The mechanism of nitrogen utilization is known for only a few groups of algae; but some green algae of the Order Chlorococcales show a preference for ammonia nitrogen, although they are able to use nitrate in the absence of ammonia. There is some indication that nitrogen plays a more important role in life processes of algae than in higher plants - at least it is more concentrated in algal bodies. Supplies in the Missouri River appear adequate to promote algal growth to a troublesome level under favorable environmental conditions.

Smaller streams usually exhibit some variation in nitrogen compound content that is associated with discharge. Certain amounts of such compounds originate in drainage over and through soils, and some augmentation usually follows a period of rainfall. If constant sources of nitrogen compounds, such as sewage discharges or drainage from livestock feeding areas, are involved, the effect of high discharges is normally dilution. Unavailability of dependable data regarding organic and nitrate nitrogen content for the period January - June, 1953, does not permit study of nitrogen compounds in relation to discharge variation in the Missouri. Indirect evidence that discharge is involved is offered by algal density variation, which is discussed later.

Phosphorous

Individual phosphate (PO_4) data and monthly total phosphorous averages appear in Table 5. Phosphate in quantities exceeding 0.01 ppm. occurred only at Williston and Bismarck. Existence of phosphate

is normally quite ephemeral and its usual occurrence at Bismarck indicated a fairly constant source of supply.

Total phosphorous concentration was not especially great at any sampling locality. Slightly higher averages at Pierre and Omaha are not considered particularly significant.

Phosphorous is a very essential element in algal growth, and very small concentrations, probably in many instances less than minimum measurable amounts, are sufficient to promote significant algal densities. Phosphorous originates in soil formations (rare), in fertilizers and animal wastes subjected to land wash, in fecal matter of aquatic animals, especially waterfowl, and in sewage and waste discharges. Common use of detergents in the past few years has increased phosphate content of domestic sewage, and has thereby augmented algal growths in some localities. Phosphate content of small streams has been noted to increase sharply following rains and then almost as quickly to disappear (4, 5, and 6). This fact leads to the suspicion that in the majority of instances phosphorous originates on the surface or in upper layers of soil when pollutional influences, etc., are not involved. The usual rapid disappearance of phosphate suggests its immediate utilization by aquatic life. Phosphorous, although no more essential than nitrogen to algal life, is usually more critical as its sources of supply are considerably more limited.

Miscellaneous Chemical Features

Other chemical analyses (calcium, magnesium, silica, fluoride, sodium, potassium, sulfate, copper, and zinc) conducted at some stations (Tables 6a - g) during the first 11 months of the investigation were designed to permit additional insight into alkalinity-hardness

relationships (if these proved atypical), to evaluate a feature (silica) which might possibly be a limiting factor to diatoms, to check on fluoride variation, and to determine if copper and zinc were sufficiently concentrated to interfere with bacterial activity. Hardness alkalinity relationships were of the usual sort, and no discussion of Ca, Mg, Na, K, and sulfate is merited. No limitation upon diatom growth may be ascribed to silica levels observed; and copper and zinc were too low to be expected to restrict bacteria. Fluoride variation was not very great, but uniform concentrations may not be expected at any water plant.

Discussion of Chemistry

Chemical water quality of the Missouri River, like that of any stream, is determined by the nature of erodable materials in and on soils of its drainage basin, by biological processes operating both in the river and in soils, and by the nature and extent of contributed man-made pollution.

Previous surveys of the Missouri River (1 and 7) have shown the existence and influence of heavy pollutional discharges at Sioux City and Omaha. For the period July 1950 - January 1951(1), samples taken from the Sioux City combination Bridge averaged 1.94 ppm. total, organic nitrogen and 1.68 ppm. total phosphorous as P; samples from the Council Bluffs, Iowa, water intake averaged, over the same period 1.60 ppm. total nitrogen and 2.09 ppm. total P. These Council Bluffs averages are considerably greater than those of samples taken from the Omaha water intake over the course of the present study, and this difference indicates that the location of the Omaha intake is well situated to avoid or minimize entrance of local pollution. The Council

Bluffs intake, about 7 miles downstream, is below entrance of the Bridge Street, Mormon Street, and Minne Lusa Sewers from Omaha, whose combined discharge contains approximately 126,200 population equivalents. High nitrogen and phosphorous values obtained at Sioux City and Council Bluffs represented local pollutional effects. Omaha intake samples showed little chemical effects of upstream pollution (e.g. Blair, Nebraska, and Sioux City) during warmer seasons, and only slight changes (e.g. pH, alkalinity) were attributable to the greater downstream extent of such pollutional influences during colder weather.

Water chemistry at Pierre, Chamberlain, Fort Randall, and Yankton was not indicative of pollutional influences. At Bismarck and Williston certain chemical features and their variation (phosphate, nitrite, nitrate, pH, and alkalinity) were characteristic of water containing considerable decomposable organic matter. Bismarck sewage enters the river about 3/4 mile below the water intake, and sewage from Williston is discharged into the mouth of Little Muddy Creek, which enters the Missouri 2 miles below that water intake. It seems hardly possible that discharges from these two sewers would effect water quality at the respective water intakes; and a detailed investigation of each local situation is considered desirable. Frequency of phosphate occurrence and high concentration of nitrite and nitrate nitrogen are suggestive of local and not general conditions in those two reaches of the river. Phosphate determinations made along the Yellowstone River[8] in August and September 1952, averaged 1.03 ppm., and concentration at most stations was 1.00 ppm. or greater. However, it would appear that effects of the Yellowstone discharge would be more evident at Williston than at Bismarck

(Table 5), and the Yellowstone may not be credited with much influence upon nitrite or nitrate levels at either station.

At stations not contaminated by local pollution (and excepting Williston and Bismarck) biological actions involved in organic decomposition were chemically insignificant, while those associated with photosynthesis were detectable to a slight extent in May and became noticeable after clear water was provided during warmer seasons by Fort Randall Reservoir. From the standpoint of water treatment, chemical quality change resulting from reservoir construction and increased photosynthetic activity is to date on the credit side of the ledger.

Biological Features

Benthic Algae

Occurrence

Prior to July 1953, benthic (bottom inhabiting) algae were observed only in tributaries. Dependence upon light for photosynthesis usually restricts these growths to shallower regions of streams, and they normally attain their greatest development on riffles and rapids. In larger streams they occur along margins and attached to upthrust timber and other structures that closely approach the surface. Practically all tributaries examined have contained dense bottom growths, at least in some localities.

Following recession of the 1953 June rise, when turbidity reduction occurred, benthic algal growths became evident all along the Missouri River from Fort Randall to Yankton. They were more numerous along margins but attained considerable concentration on partly submerged trees, water intakes, bridge pillars, etc. Walls that were wet with spray from discharges through the tunnels at Fort Randall Dam were covered with algal growths all summer and fall; and algal growths occupied upper submerged portions of the walls, the lowhead dam, and other concrete structures in the channel below the tunnels from October to December.

Composition

Cladophora, a branched filamentous green alga, was often the predominant benthic form in tributaries and the main stem. Its greatest concentration was observed in the Big Horn River below Boysen Dam, but its growth was quite luxuriant in other streams, along margins of the clarified stretch of the Missouri, and on structures just

below Fort Randall Dam in autumn of 1953. In shallow areas, particularly on riffles or rapids, Cladophora growths, due to optimum light intensity and temperature relationships, are usually present in late winter and spring, and again in fall and early winter. In larger streams, where they usually exist only in scattered small patches, they may persist over the entire growing season. Cladophora growth below Fort Randall Dam in the fall probably represented a seasonal response facilitated by lowered discharges. Summer algal growths on the moist walls were composed of Batrachospermum and Phormidium, the former often imparting a pink color to the walls.

Attached to Cladophora filaments were many diatoms of the groups referred to the facultative planker category in the phytoplankton section. In some instances, especially in the fall of 1953, isolated growths were found to consist entirely of diatoms, with many species attached to a framework provided by filaments of Diatoma vulgare. Assemblages of this sort had a characteristic blackish green color.

Benthic algal growths fill an important niche in the productivity structure of many streams, and may, during periods of deterioration and dislodgment, occasion nuisance conditions (see Big Horn River section). In the Missouri River their main relationship to water quality appears to be contribution of displaced individuals to the phytoplankton.

Plankton

Methods of Study

Plankton samples were collected in 8 or 12 ounce bottles and preserved with formalin. Suspended sediment interfered with plankton

analysis, and at first it was mandatory to perform this task on 1 ml. portions of straight unconcentrated or even diluted samples. In the interest of uniformity of results this method was continued all during the investigation, even though ice cover and later impoundment in Fort Randall Reservoir at times and/or at certain stations sufficiently reduced turbidity to permit concentration methods. Analyses of straight samples, particularly if the entire area of the counting chamber is covered, give accurate results for those organisms observable at magnifications up to 200 diameters whose concentration amounts to at least 1 per ml. (1,000 per l.). This method is not satisfactory for larger organisms whose numbers frequently fall below 1,000 per l, unless several 1 ml. portions of each sample are analyzed. Checks on the occurrence of larger organisms were provided by a certain number of supplemental net concentrated samples taken when and where turbidity conditions permitted.

In waters containing considerable amounts of inanimate suspended matter it is not possible to determine weight of living plankton; and volume may be arrived at only by visual measurement and enumeration under a microscope. Volume of those organisms of uniform geometric shape, cylinders, spheres, cubes, etc., may be accurately estimated by this method; however, volume of irregularly or inconsistently shaped forms may be only approximated, particularly if there is considerable variation. In determining volumetric units by the visual method, measurements of a significant number of individuals of each species must be averaged and unit volumes computed from the mean dimensions. Volumes may be expressed as cubic microns, cubic millimeters, parts per million by volume, or as volumetric units

referred to the average size of one numerous organism. The last named system is often preferable since it involves less computation and still reduces results to a common denominator. This system is utilized in expressing plankton densities in this report. The standard unit of volume (the M unit in tables and figures) is equivalent to the average sized specimen of Melosira granulata angustissima, the most numerous plankter following reservoir impoundment. Average sized colonies of this species were cylinders 600 microns long and 5 microns in diameter. M units may be converted into approximate parts per million by volume by multiplying by 0.011175. One thousand M units per ml. are equivalent to an algal thread 5 microns in diameter and 1.43 miles long in each gallon of river water. M units, given at the bottom of Tables 9, 10, and 13, refer only to total volume of phytoplankters per ml. Numbers in the bodies of these tables indicate actual numbers of each group per ml.

Phytoplankton

Qualitative Features:

At magnifications usable with a standard plankton counting cell it was not possible to determine the species of a large number of organisms observed. Identification of such organisms was accomplished by use of special preparations at higher magnification. Some organisms could not be identified beyond Genus, and some could not be found in smaller volumes used for higher magnification. Similar or closely related forms were lumped into groups for enumeration at lower magnification. Designation and composition of the various groups are shown in Table 7.

The number of various groups represented at each station is

shown in Tables 9a-g. In the majority of instances diatoms were predominant at each station, but Chlamydomonas was often more numerous during cold weather.

The phytoplankton population of the Missouri, like that of most streams, consisted of a mixture of true plankton organisms and displaced benthic (bottom) forms (facultative plankters). Organisms representing the true plankter category are indicated by asterisks in Table 7 - others are facultative plankters originating in benthic growths. The distinction between true and facultative plankters is not one that may be expected to cover various environmental situations, because some forms (e.g. Chlamydomonas, Euglena) are upon occasion greatly concentrated either as benthic or plankton forms, and sometimes as both. Organisms assigned to the facultative group in the Missouri River attained by far their greatest mass in attached growths in various tributaries, and in the Missouri River below Fort Randall Dam.

Seasonal Variation: Seasonal qualitative variation of predominant forms at each station is summarized in Table 8. With few exceptions, at least one of the three generally most numerous groups each month was present at all stations. Frequently the same three groups were most abundant at each locality, although not always in the same order; and in some instances a single group dominated at all stations sampled. Seasonal qualitative similarity at various stations was evident before and after impoundment at Fort Randall Reservoir, at stations in affected and unaffected reaches of the river.

Tributary and Main Stem Comparison: The sampling and analysis schedule related to the main stem allowed little time for examination of tributaries, and the Niobrara and Big Horn Rivers were the only ones sampled during this investigation. However, the 1950 study(1) and records available from previous pollutional surveys(8, 9, and 10) indicate that tributaries, especially with regard to dominant groups, differ widely and maintain individually characteristic plankton populations. In general, tributaries contained a greater number of plankton species, and in some of them groups other than diatoms or Chlamydomonas were at least seasonally predominant. On September 1, 1953, the Niobrara River contained 27 plankton groups with Dictyosphaerium (1352 per ml.) and Scenedesmus dimorphus (327 per ml.) as dominant species. Dominant plankters in the Missouri at Yankton on that date were Melosira (a) and Cyclotella-Stephanodiscus gr. Only 9 groups were common to both the Niobrara and the Missouri at Yankton, and six of these were also present below Fort Randall Dam. On September 29, 1953, qualitative relationships between the Niobrara and the Missouri were essentially the same, although the Chlamydomonas and Navicula groups were then predominant in the Niobrara (Tables 9f and 10). In September 1952, predominant plankters in the Yellowstone River(8) were Navicula gr. and Diatoma vulgare. The plankton population in the Big Horn River at that time differed somewhat from that in the Yellowstone. The then dominant forms in the Yellowstone did not predominate at any Missouri River station at time. Fifty-one different groups composed the Yellowstone phytoplankton population, while 23 groups were the most observed at any Missouri River station during the same period. The 1950 study(1) also demonstrated tributary individuality.

Greater plankton variety in tributaries indicated generally more favorable environments than that offered by the main stem, at least during the greater part of the period covered by this report. Factors contributing to more favorable plankton conditions in the smaller streams require individual evaluation, but some factors of importance were as follows: turbidity was usually very low for extended periods; great extent of shallow areas permitted more luxuriant bottom growths in many cases; lower discharges allowed local nutrient enrichment to be more effective; current velocity was frequently lower; reservoirs often were influential; waterfowl refuges sometimes offered considerable nutrient enrichment; etc.

Origin of Main Stem Phytoplankters: Seasonal similarities of dominant plankters along most of the 1012.2 mile stretch of the Missouri indicate that conditions therein result in development of a characteristic plankton population. The 1950 investigation[1], which covered a more limited period of time, led to the belief that the Missouri developed no especially distinctive plankton population, but rather that most organisms were introduced by tributaries and had relatively short survival periods in the main stem. This impression was gained from the occurrence of meager plankton densities in the Missouri except below the mouths of certain tributaries, where, in each instance, the greater concentrations were qualitatively characteristic of the nearest upstream tributary. If this condition generally prevailed, the main stem would be expected to exhibit striking qualitative differences in dominant groups at various stations. However, close similarities were evident most of the time, especially in the stretch from Pierre to Omaha.

Phytoplankters found in the Missouri undoubtedly originated in tributaries, but, in view of tributary differences, it appears that no tributary inflow may be credited with any special influence. Predominant organisms in the Missouri were, with five exceptions, either Chlamydomonas or diatoms. The five exceptional instances involved the Gomphosphaeria-Coelosphaerium group upon two occasions at Bismarck and once at Pierre. Gloeocystis once outnumbered any other group at Pierre, and Trachelomonas was once predominant at Bismarck. The sporadic occurrence of the Gomphosphaeria-Coelosphaerium group among dominant classes at Williston, Bismarck, Pierre, and Yankton may have represented local tributary influences similar to those reported for the James and Vermillion Rivers in 1950(1).

Benthic algal growths, source of most facultative plankters, and common in tributary streams, were very rare or nonexistent in the Missouri prior to formation of Fort Randall Reservoir. Therefore, occurrence of facultative plankters in the main stem prior to July 1953 must be assumed to indicate their general origin in tributaries. This relationship suggests that all groups normally originate in the smaller streams. Establishment of characteristic seasonal populations in the Missouri from a variety of distinctive plankton assemblages from tributaries must necessarily involve elimination of tributary forms incapable of surviving conditions in the big river. Numerical superiority of any group in any tributary would therefore only locally influence the main stem, unless such a group was one of the apparent few with greater tolerance. Survival rate of any introduced group appeared to be low except at certain

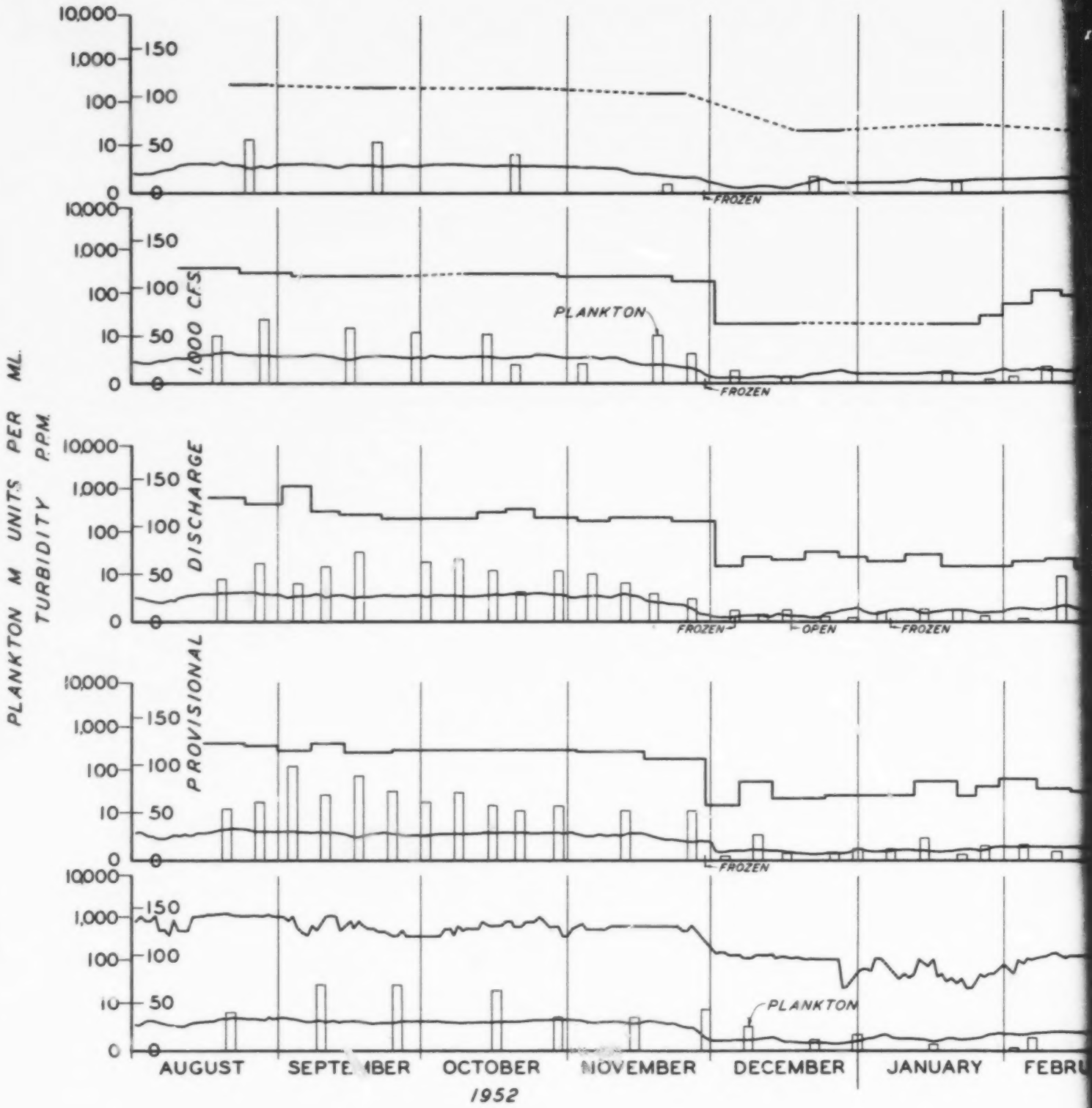
seasons. Environmental conditions, by virtue of lower turbidity, were improved in certain reaches by Fort Randall Reservoir.

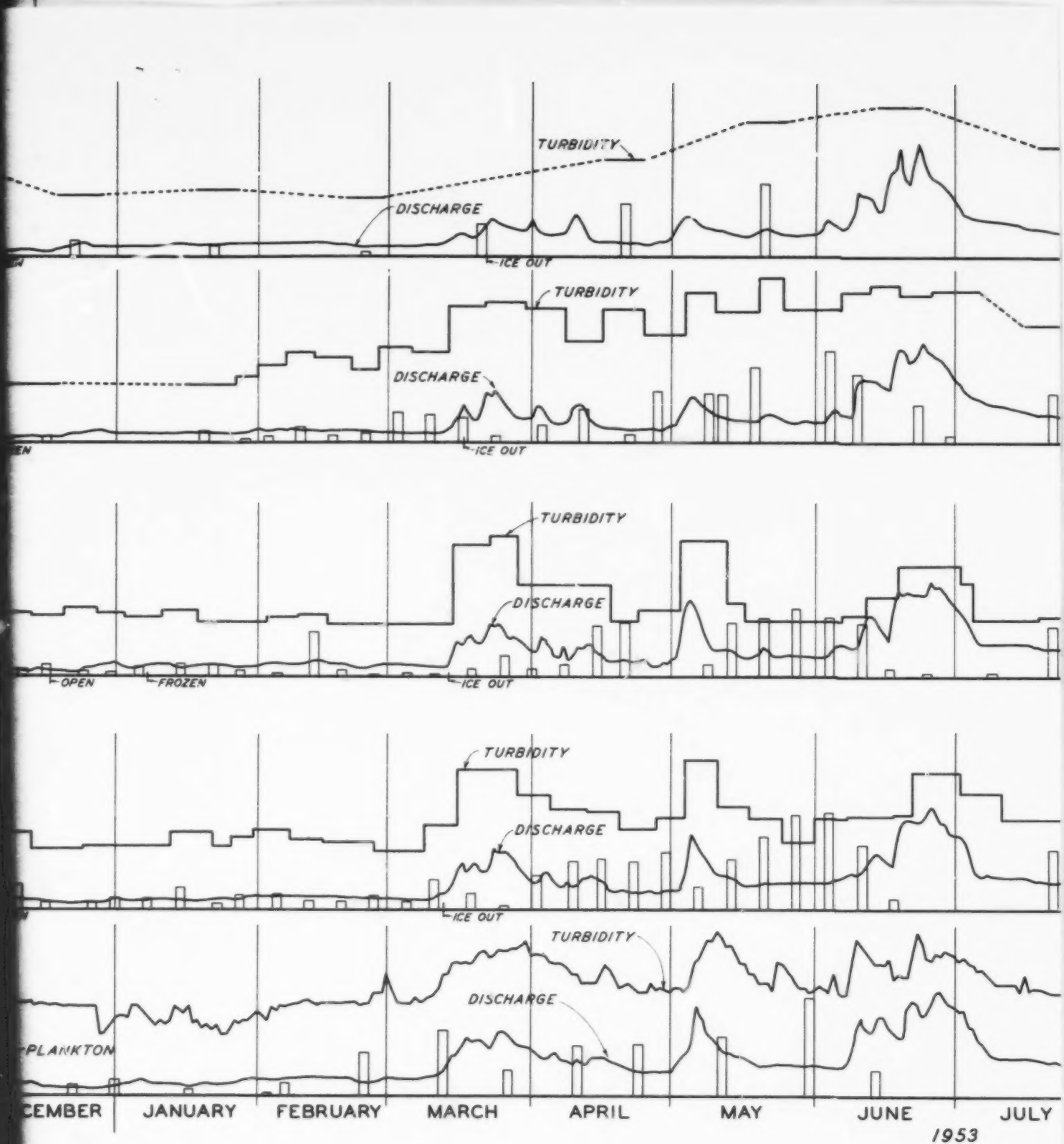
In final analysis it would appear that the characteristic seasonal populations in the Missouri result from a screening process that permits survival of only definite groups, no matter what their degree of dominance in tributary situations, or their points of origin. It should be pointed out that tributary differences were mainly involved in dominant groups, since in most instances organisms found in the main stem were represented in tributaries. To date Fort Randall Reservoir has had little effect upon qualitative aspects of the plankton population. Groups that have developed to dominant positions in it and its discharge have also been predominant in the river above. Lack of influence along this line probably resulted from a filling procedure that did not allow significant retention of any seasonal runoff.

Quantitative Features:

The greatest concentration of organisms observed in the main stem was slightly more than 3,000 M units per ml. Over extended periods, particularly during ice cover and high discharge seasons, plankton density was quite low - frequently less than one M unit per ml. Available records(8, 9, and 10) indicate that numbers were generally much higher in the majority of tributaries - a difference also indicative of plankton attrition in the main stem.

Seasonal Variation: Variation in phytoplankton volume at the four South Dakota stations and Omaha is associated with seasonal discharge and turbidity changes in Figure 7. Ignoring influences of Fort


PLANKTON M UNITS PER ML.
TURBIDITY P.P.M.
10,000
1,000
100
10
0
150
100
50
0
FROZEN
PLANKTON
1,000 CFS
DISCHARGE
PROVISIONAL
OPEN
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
1952


TURBIDITY
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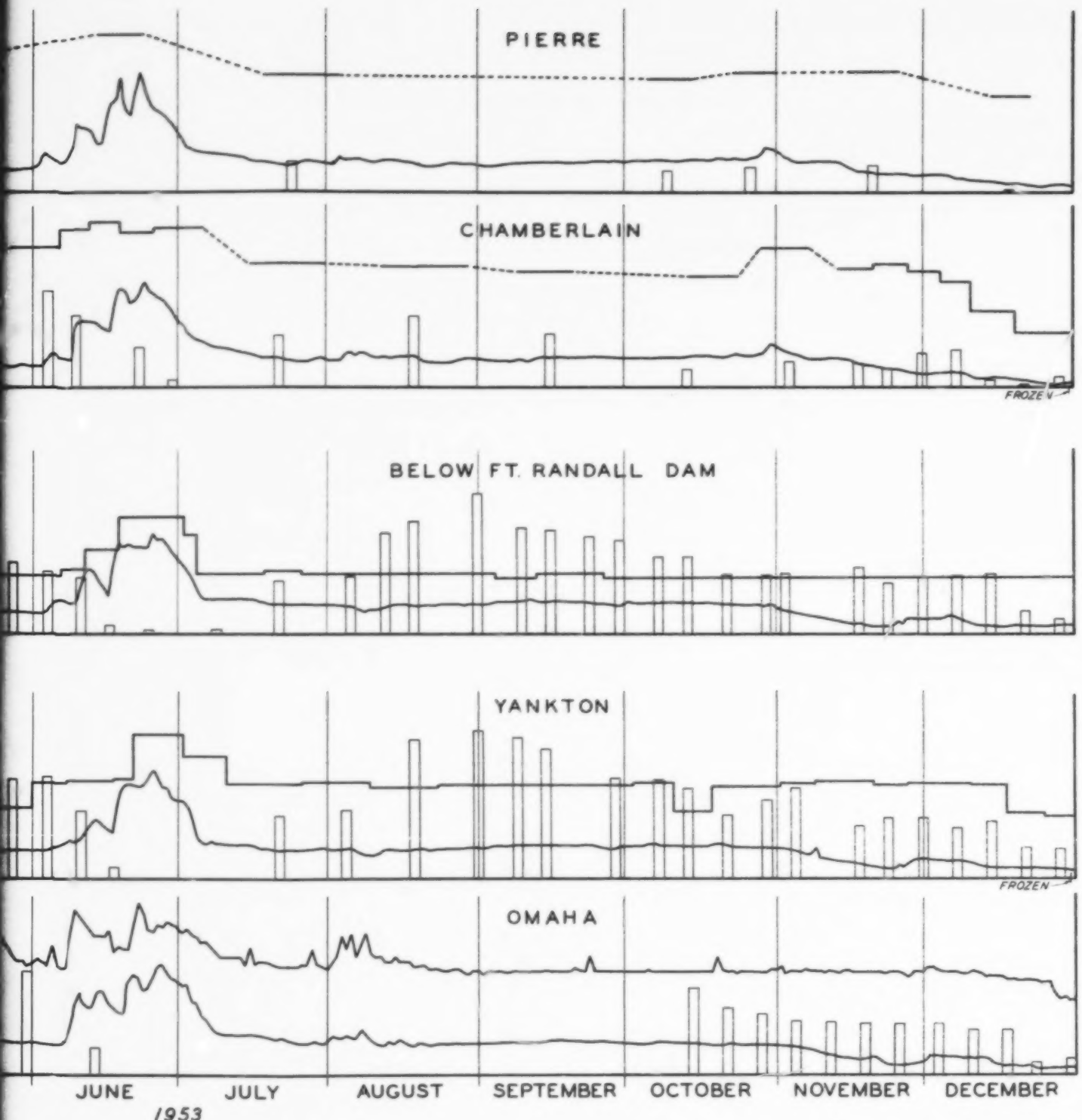
DISCHARGE
ICE OUT
TURBIDITY
DISCHARGE
PLANKTON
CEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
1953

58-a FIGURE 7



CENTRAL MISSOURI RIVER

PLANKTON DENSITY, DISCHARGE & TURBIDITY

AUGUST 1952 - DECEMBER 1953

Randall Reservoir, it may be noted that greatest plankton densities occurred during the low flow period that endured almost a month between the 1953 May and June rises. Plankton increase to a lesser extent characterized lowered discharges following the general period of high stages in March and early April. Densities were relatively high during the August to November periods when the river received highest releases from Fort Peck and exhibited rather uniform discharges. Lowest concentrations were associated with ice cover and high discharges.

Relationships of plankton density to discharge do not necessarily indicate a simple dilution - concentration process. Considering physical features alone, the period from August to November, by virtue of its uniformity of discharge and relatively low turbidity, was seemingly more suited to plankton growth than times intermediate to high spring and summer discharges. Increased concentration of nutrient elements in streams following periods of increased runoff has been noted(4, 5, and 6) and it appears likely that greater algal production following high stages was associated with chemical as well as physical improvement of their environment. Algal increases at those times cannot be referred to tributary inflow as they characterized all stations and were due to one or two predominant groups (Tables 9a - g).

Reservoir Influences: Fort Randall Reservoir discharged an almost constant supply of clear water after recession of the June rise. The maximum observed plankton concentrations developed below the reservoir about one and one-half months later. A progressive downstream increase was evident all the way to Yankton - the lowermost station

sampled during July, August, and September (Tables 9e - f, Figure 7). A few organisms introduced by the Niobrara River were present at Yankton, but continued growth and proliferation of forms discharged from the reservoir were the major factors involved. Greater plankton growth below than in reservoirs has been noted in other parts of the Missouri Basin(1 and 10). In some instances nutrients arising from oxidation of anaerobic hypolimnion discharges were involved, while in others no measurable environmental factors were detected. It is a general limnological principle that greater productivity characterizes closer relationships of photosynthetic and decomposition zones when other conditions are the same. Below Fort Randall a closer relationship than that which existed in the reservoir was possible, and, at this time, may be assumed generally responsible for the increased phytoplankton growth. If rivers below reservoirs are very shallow (2-4 feet) benthic algal growths may usurp priority and reservoir plankton may decline. This state of affairs was noted below Alcova Dam in the North Platte River in 1950(10), in the Big Horn River below Boysen Dam in May 1953, and below Fort Randall Dam when releases were cut down in November, 1953. Reference to Table 3 will indicate the influence of these bottom growths in increased oxygen supersaturation below the reservoir. Although the maximum plankton concentration did not occur within the reservoir, it may be safely assumed that clarification and other phenomena associated with its formation were responsible for maximums observed farther downstream. The extent of greater densities below Yankton is not known from samples. At Omaha, from October to December, 1953, plankton concentration was greater than

during the same period in 1952.

Previous investigators[1 and 2] were of the opinion that curtailment of phytoplankton growth in the Missouri River was largely caused by excessive turbidity and high current velocity. There seems little reason to doubt that turbidity was an important factor, but current velocity in the Missouri is apparently not as much a limiting factor. Discharge below Fort Randall Dam and at Yankton was practically the same during the August - November period in 1952 and 1953, but the river developed greater plankton density than the reservoir when clear water was provided.

Net Plankton:

Net collections were instituted on a monthly basis at Chamberlain, Fort Randall, and Yankton early in 1953. Concentrated samples were considered desirable after analyses of straight samples failed to disclose the presence of Ceratium hirundinella, which had been widely distributed in Wyoming and Montana tributaries - and responsible for taste and odor problems at some localities - during the fall of 1952.

Phytoplankton content of net plankton samples appears in Table 11. These samples, concentrated from six liters, were representative of greater volumes of water, and consequently exhibited greater variety of forms than straight samples collected on or near the same dates. They demonstrated the presence of Ceratium and other forms that were largely missed by straight samples. Quantitatively, the net samples did not as accurately represent the population, a fact reflecting the general tendency of concentrated samples to underestimate plankton density due to actual losses incurred in concentration processes and apparent losses traceable to time imposed

restrictions upon analysis of truly representative volumes of samples.

Zooplankton

Concentration of zooplankters, usually less than one per ml., was too low to permit their regular detection in the routine, straight sample analyses. Net samples from three river stations and Fort Randall Reservoir showed the presence of these forms when conditions were most favorable for development of the phytoplankters. Fort Randall Reservoir contained the assemblages shown in Table 12 in August and September, 1953. The same forms were evident just below the dam and at Yankton in about the same concentration they attained in surface water of the reservoir.

During spring and early summer phytoplankton increases, net plankton samples showed the occurrence of Keratella cochlearis, K. Cephalodella sp, Polyarthra platyptera, Diaptomus sp., nauplii, cyclopodids, Didinium sp. Vorticella sp., and Difflugia globula at Chamberlain, Fort Randall Dam, and Yankton. Total concentration of these forms varied from 30 to 90 per liter.

Fort Randall Reservoir

Routine sampling and study of this reservoir began in July 1953. Most water quality features characteristic of it were evident in samples taken from the discharge - descriptions of which have been presented in preceding sections. Routine reservoir samples were taken a few feet below the surface, and upon occasion surface water differed in some aspects from that discharged through the tunnels situated at the floor of the reservoir. These differences were mainly related to biological features - aggregations of

plankters at certain depths.

Intake apertures drew water from all reservoir levels and their discharge was therefore more representative of the reservoir on the whole than surface layers of the lake. A summary of reservoir phytoplankton analyses appears in Table 13, and differences in plankton density between reservoir surface and discharged water may be noted by reference also to Table 9e. During the beginning of the Melosira (a) bloom (August 4, 1953) surface water concentrations were considerably less than those obtained at depths of 15 to 30 feet. This nonuniformity of vertical distribution was the basis for plankton density differences between reservoir surface and discharged waters noted on that date. Other differences may be noted in the two tables. On September 15, Melosira (a) concentrations had moved toward the reservoir surface, and from then until this organism disappeared in late November, reservoir densities appeared greater. Differences were also evident in concentrations of other phytoplankton groups.

Chemically, the reservoir surface differed from discharged water only with respect to oxygen and total organic nitrogen concentration. The latter was almost uniformly greater in the reservoir surface layers. Individual analysis results at the two stations (total N in ppm.) were as follows:

	Fort Randall Reservoir	Below Fort Randall Dam
7/21/53	1.40	1.17
8/12/53	1.70	0.82
8/18/53	0.94	0.89
9/9/53	2.34	1.37
9/23/53	0.35	0.22
10/7/53	0.17	0.30
10/21/53	0.07	0.79
10/29/53	0.10	0.15
11/2/53	0.20	0.15
11/16/53	0.72	0.50
11/30/53	0.25	0.25
12/14/53	0.17	0.30

Only reservoir surface samples were analyzed for total nitrogen. Oxygen differences and reasons behind them have been mentioned in a preceding section. Temperature of reservoir and discharged water were always the same; and, as previously stated, no thermal stratification was evident in the reservoir when vertical measurements were made in August and September.

Shallow regions of the reservoir in the area contiguous to the dam developed very dense Cladophora aggregations when the water level declined in September; but these growths, many of which were left high and dry as the lake level continued to fall, contained few of the diatoms that commonly inhabit Cladophora filaments in streams.

Big Horn River and Boysen Reservoir

Boysen Reservoir is situated on the Big Horn (Wind) River at the head of Wind River Canyon, approximately 21 miles south of

Thermopolis, Wyoming. That region of the Big Horn has been very turbid since development of the Riverton Irrigation Project which drains to Five Mile Creek, now emptying into the reservoir.

Impoundment of Boysen Reservoir began in November, 1951. Inasmuch as this reservoir was affecting what had previously been a very turbid stream, it appeared that study of it and its influences upon the Big Horn River might offer information pertinent to the Fort Randall Reservoir situation on the Missouri River. Two field studies (September 1952, May 1953) were made to secure general limnological information; and the Wyoming Department of Public Health collected three series of samples to supplement plankton data obtained during the field investigations. The following account is a brief resume' of the results of these studies.

Sedimentation in the reservoir reduced turbidity to less than 25 ppm. and the river below was transformed into a clear, cold trout stream. Downstream extent of clear water in this river now depends upon amounts of discharge in intermittent tributaries and irrigation returns; but experience indicates that it should always be clear for about 17 miles below the dam, clear most of the time down to Owl Creek below Thermopolis, and clear a large part of the time down to Worland.

The winter of 1952-53 was milder than usual and ice and snow cover were of short duration.

Reservoir influences upon water chemistry were most plainly evident in reduction of hardness and alkalinity. Thermal and chemical stratification were present in September 1952, but only the lower most 2 feet of water differed from the surface. In May 1953 the lake was homogenous thermally and chemically from top to bottom. Hardness

and alkalinity were considerably lower in May than in September. Discharge to the river below (through penstocks) varied from 560 to 1,100 c.f.s. over the period of study.

Plankton development within the reservoir included a very dense bloom of Ceratium in fall of 1952, and fairly concentrated diatom growths (Fragilaria crotonensis, Diatoma elongatum, Asterionella formosa) during winter and spring. Lake plankters were discharged to the river below the dam. Ceratium concentrations were as great in the stream as in the reservoir. Diatom densities during winter and early spring exhibited a decrease in the river for about 20 miles below, but then increased in number below discharges of raw sewage from each downstream municipality. These plankters occasioned taste and odor problems in municipal water supplies taken from the Big Horn River. Very dense aggregations of Cladophora (and some Stigeoclonium) occupied most of the river bottom from Boysen Dam to below Thermopolis in the fall of 1952, and again in the spring of 1953. These growths were inhabited by the usual diatom assemblage, from which many individuals were displaced and carried in suspension. The Cladophora growths were deteriorating and breaking loose from the bottom in May 1953, and the river was freckled with floating green fronds over the entire distance studied (Boysen Dam to Greybull). These floating algae clogged water intakes of factories and water plants and necessitated frequent cleaning of screens. They were probably also involved in taste and odor problems occurring at that time, although a fairly dense plankton diatom population was also present. The clear, shallow water; rocky stream bottom; and decreased

light intensity, furnished in late spring by high canyon walls; combined to provide, in the first 17 miles below Boysen Dam, the most ideal Cladophora habitat noted to date by the investigators. Clarification of this river has imposed new difficulties upon water treatment; and has made much more critical the discharge of untreated sewage, which provides nutrient enrichment that has been observed to stimulate phytoplankton growth. On the credit side, a worthwhile trout fishery has been developed.

Algal growth associated with formation of Boysen Reservoir resembled in some respects developments in the Missouri after impoundment of Fort Randall Reservoir. However, the much shallower depth of the Big Horn River permitted benthic growths to stake first claim on the more favorable conditions below its reservoir.

Council Bluffs Settling Basins

The first of these basins was filled August 17, 1952. Other basins were filled and drained at intervals and study of the situation continued until January 20, 1953. The old water works property was sold in late December and the basins were drained in late January. All basins leaked and only short periods of study were possible after each filling.

The various basins exhibited considerable individuality in physical, chemical, and biological aspects. Each developed a goodly concentration of plankton, qualitative aspects of which differed from basin to basin, and with different fillings of the same basin. Dominance among the phytoplankton group was attained, in various basins and at different times, by: (1) the Chlorococcales group of green algae; (2) diatoms (Cyclotella glomerata); (3) the

Chlamydomonas gr.; and (4) Euglena and Trachelomonas. Concentration varied from 25,000 to 11,000,000 organisms per liter. The most numerous organism was Chlamydomonas. Qualitative differences were assumed to result from variation in biological quality of river water at different times of filling, variation in depth among basins and in individual basins at different times, and the tendency of separate bodies of water to differ for various other reasons. Chemically, all basins showed oxygen and pH increase, alkalinity and hardness decreased, and ammonia and nitrite nitrogen increase, the latter following development of zooplankter populations.

In view of later developments, study of these basins offered little information pertinent to the Fort Randall Reservoir situation on the main stem. They did show that under favorable conditions Missouri River water has a high productivity. However, water caught in them contained some enriching elements from upstream sewage discharge, and was probably more productive than that in the region most influenced by the reservoir.

Oxbows

Investigation of oxbows was at first limited to those of more or less temporary nature that receive new water from each significant river rise. It was found that oxbows of this type are too temporary in nature to permit much algal development. Two permanent oxbows that were investigated were quite different from each other and from any other clarified portion of Missouri River water examined.

Taste and Odor Development

Problems arising from poor biological water quality were infrequent or unheard of prior to August, 1953, at establishments utilizing Central Missouri River water. Water works operators at Bismarck, North Dakota, Yankton, South Dakota, and Council Bluffs, Iowa, have experienced a few brief periods of taste and odor difficulty in spring and early summer. They assumed that such problems were occasioned by organic materials brought into the river from surface runoff, pothole drainage, etc. No operator could recall any extended duration of such difficulty, or trouble at seasons other than the general high runoff period in spring and early summer.

Increased phytoplankton density and its after effects in the river at Yankton following reservoir impoundment produced distinctly unpleasant tastes and odors that required adoption of specific treatment for a period of about 5 months. On August 21, 1953, the Public Health Service advised the Yankton water superintendent, through the South Dakota State Department of Health, of impending plankton increase to a nuisance level. Activated carbon treatment was instituted at the water plant upon receipt of this information. However, on August 26, the night operator neglected to maintain carbon application, and on the following day a very unsavory taste was evident in treated water. The water plant received many complaints from consumers, but was able to control the odor by increased dosage with activated carbon and chlorine. A slight taste present in finished water on September 15, 1953, despite continued increased carbon and chlorine application, was of short duration and did not elicit much response from consumers. Carbon application was

discontinued for a week in mid-October, but was re-established when many complaints poured in on October 24. Following this experience, carbon treatment was continued through December, 1953.

The taste and odor problem, unique in the experience of Yankton water works operators, continued for several weeks after plankton densities declined to a much lower level (Table 9f and Figure 7). This occurrence indicated taste and odors attributable to compounds and organisms associated with phytoplankton decay. For many years the direct role of algae in taste and odor production was unquestioned, although little information was on hand concerning types and exact sources of chemical complexes involved. Recently the Actinomycetes group of fungi have been associated with taste and odor occurrence in surface water supplies[11]. The culpability of the ray fungi has been demonstrated in some turbid situations; and, in Texas at least, tastes and odors developed during "blooms" of Melosira and Anabaena were observed to occur only when these algae were attacked by Actinomycetes. In a situation like the Missouri River below Fort Randall Dam it would appear that a dense phytoplankton population is necessary to initiate the chain of events leading to extended duration of taste and odor difficulties.

Reservoir Influences upon Other Aspects of Water Treatment

Water works operators at Yankton and Omaha have expressed the opinion that changed physical and chemical water quality attributable to reservoir impoundment has to date facilitated treatment. Yankton water treatment is of the rapid filtration type with hardness reduction. Comparison of pounds of chemicals used for treatment (per one million gallons of water) over the last 6 months in 1952 and 1953

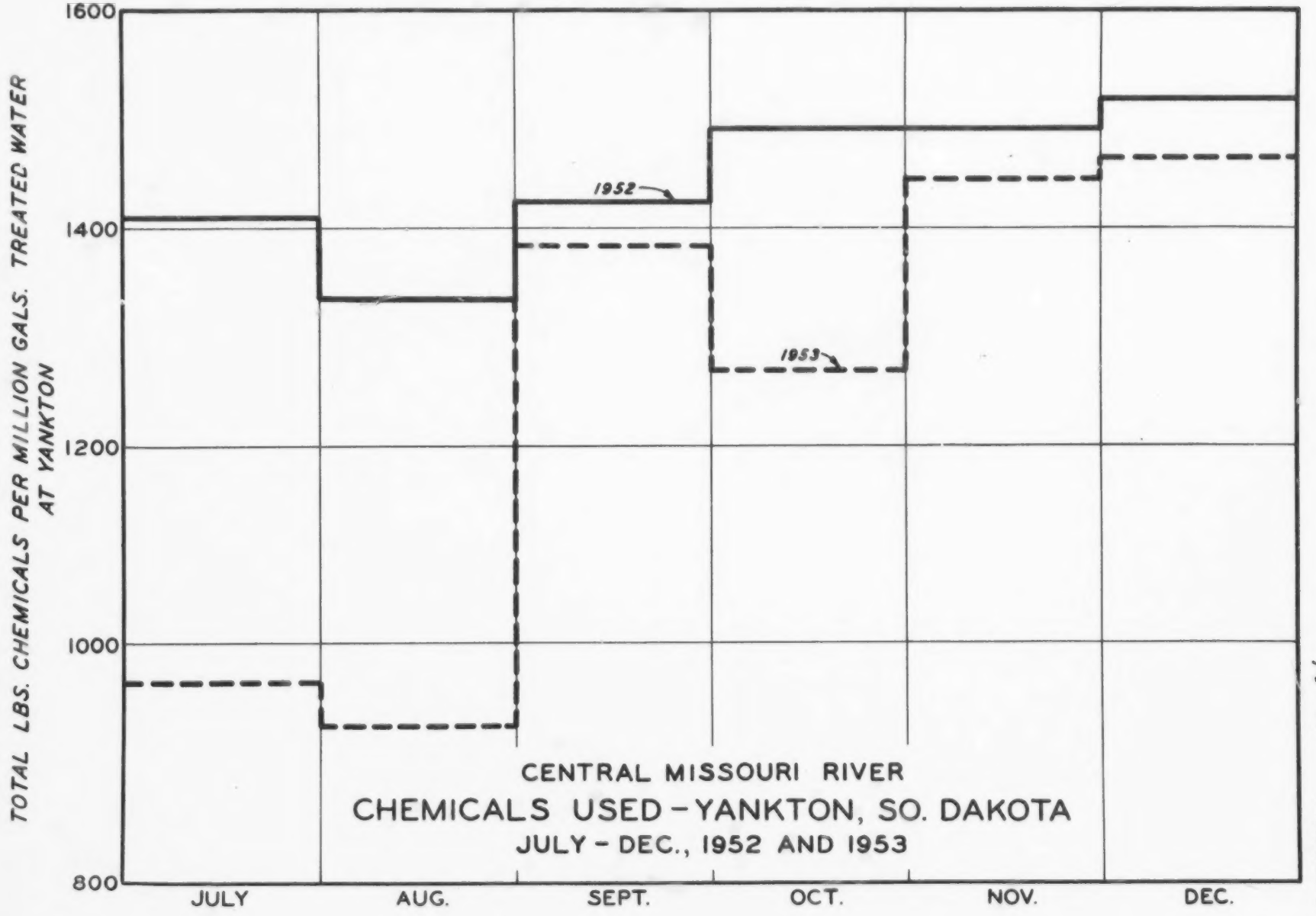

TOTAL LBS. CHEMICALS PER MILLION GALS. TREATED WATER AT YANKTON
1600
1400
1200
1000
800
1952
1953
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
CENTRAL MISSOURI RIVER
CHEMICALS USED - YANKTON, SO. DAKOTA
JULY - DEC., 1952 AND 1953

FIGURE 8

70-a

appears in Figure 8. Treatment costs on this basis were considerably lower in 1953. Lowered and more uniform turbidity and hardness were given as factors permitting savings in chemicals. Algal growths necessitated prolonged and increased use of activated carbon, but added cost in this respect was exceeded by savings realized from lesser use of other chemicals. Uniformity of hardness was considered as important as lowered concentration. Decreased turbidity resulted in savings of coagulants.

At Omaha, where softening is not practiced, greater ease of water treatment was related only to lowered turbidity.

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APPENDIX

Table 1. Summary of individual temperature, pH, and alkalinity measurements

Station	Date	Temp. °C	pH	CO_3 Alk. ppm.	HCO_3 Alk. ppm.	Total Alk. ppm.
Williston, N. D.	9-10-52	19	7.2	0.0	152	152
	10-9-52	12	7.2	0.0	95	95
	12-1-52	4	7.4	0.0	198	198
	1-7-53	0	8.1	-	<200	200
	2-2-53	0	8.1	-	<185	185
	5-5-53	14	7.2	0.0	165	165
	7-2-53	-	7.2	0.0	98	98
Bismarck, N. D.	8-16-52	21	8.2	6.0	109	115
	9-10-52	21	7.5	0.0	160	160
	10-17-52	8	7.65	0.0	162	162
	11-14-52	8	7.2	0.0	172	172
	12-19-52	0	8.2	-	<208	208
	1-9-53	0	8.2	-	<190	190
	2-19-53	0	8.15	-	<176	176
	4-8-53	0	8.0	0.0	140	140
	5-12-53	11	7.8	0.0	164	164
	7-20-53	24	7.6	0.0	120	120
	8-26-53	23	7.6	0.0	150	150
Chamberlain, S. D.	8-18-52	22	8.2	6.0	124	130
	9-11-52	22	8.2	4.0	134	138
	10-22-52	9	8.4	4.3	102	106
	11-19-52	3	8.1	1.3	103	104
	12-16-52	3	8.1	2.0	99	101
	1-27-53	3	8.2	4.0	188	192
	3-10-53	2	8.1	2.3	171	173
	4-22-53	12	8.1	2.0	148	150
	5-27-53	17	8.2	4.0	156	160
	6-16-53	24	7.9	0.0	130	130
	7-21-53	28	8.1	4.0	133	137
	8-18-53	24	8.3	7.0	145	152
	9-15-53	21	8.2	5.0	142	147
	10-13-53	16	8.4	8.0	146	154
	11-17-53	9	8.1	2.0	149	151
	12-15-53	1	8.1	4.0	176	180
Below Ft. Randall Dam	8-19-52	29	8.2	6.0	118	124
	9-10-52	25	8.2	6.0	132	138
	10-21-52	11	8.3	5.0	102	107
	11-18-52	4	8.1	2.6	133	136
	12-16-52	2	8.1	2.6	97	99
	1-27-53	1	8.05	0.1	198	198
	3-10-53	2	8.1	2.0	179	181
	4-22-53	8	8.1	4.0	147	151
	5-27-53	17	8.3	10.0	153	163
	6-16-53	24	8.1	4.0	141	145
	7-21-53	25	8.1	4.0	118	122
	8-5-53	26	8.2	7.0	111	118
	8-18-53	24	8.2	4.0	119	123
	9-1-53	26	8.5	10.0	136	146
	9-15-53	21	8.5	10.0	134	144
	9-29-53	17	8.3	7.0	136	143
	10-13-53	15	8.2	4.0	144	148
	10-29-53	14	8.3	8.0	142	150
	11-17-53	9.5	8.1	2.0	145	147
	12-15-53	4	8.1	0.1	143	143
Yankton, S. D.	8-20-52	24	8.2	6.0	98	104
	9-10-52	21.5	8.3	4.0	131	135
	10-21-52	10	8.2	6.0	99	105
	11-18-52	5	8.1	2.6	101	104
	12-16-52	2	8.1	3.0	93	96
	1-27-53	2	8.1	2.0	181	183
	3-10-53	2	8.1	4.0	162	166
	4-22-53	12	8.1	4.0	146	150
	5-27-53	18	8.3	8.0	149	157
	6-17-53	23	8.1	6.0	146	152
	7-21-53	26	8.3	8.0	118	126
	8-18-53	24	8.4	8.0	111	119
	9-1-53	27	8.5	10.0	137	147
	9-15-53	20	8.4	10.0	139	149
	9-29-53	18	8.3	7.0	139	146
	10-13-53	14	8.3	4.0	140	144
	10-29-53	12	8.4	10.0	140	150
	11-17-53	9	8.1	2.0	165	167
	12-15-53	5	8.1	0.1	140	140
Omaha, Nebr.	8-21-52	25	8.0	0.0	115	115
	9-9-52	26	8.25	8.0	146	154
	10-31-52	9	8.2	6.0	157	163
	11-6-52	8	8.3	8.0	161	169
	11-13-52	6	8.3	8.0	157	165
	11-29-52	2	8.1	2.0	174	176
	12-8-52	1	8.2	6.0	202	208
	12-22-52	0.5	8.1	6.0	224	230
	12-31-52	0.5	8.0	0.0	235	235
	1-16-53	0.5	8.0	0.0	233	233
	2-2-53	1.1	8.0	0.0	205	205
	2-4-53	1.1	8.0	0.0	192	192
	2-23-53	0.5	7.9	0.0	197	197
	3-12-53	2.2	7.6	0.0	189	189
	3-26-53	4.4	7.8	0.0	183	183
	4-10-53	8	8.0	0.0	162	162
	4-23-53	11	7.9	0.0	171	171
	5-11-53	17	7.9	0.0	147	147
	5-30-53	21	8.1	4.0	199	203
	6-13-53	24	7.8	0.0	147	147

Table 2. Average Total alkalinity and Total Hardness - ppm

	Total alkalinity	Total Hardness
Aug. - Dec. 1952		
Bismarck	162	248
Chamberlain	155	229
Ft. Randall	142	183
Yankton	156	227
Omaha	177	255
Aug. - Dec. 1953		
Chamberlain	167	244
Ft. Randall	140	215
Yankton	145	220
Omaha	-	238

Table 3. Summary of individual oxygen absorbent & saturation

Date	Chamberlain	Below Ft. Randall Dam	Yankton	Ft. Randall tailwater
8-5-53	-	122.5	112	-
9-1-53	-	122.5	105	122.5
9-15-53	93	104	97.5	104
9-29-53	-	112	105	110
10-13-53	96	102	105	103
10-29-53	-	105	100	99
11-17-53	100	117	100	102
12-15-53	99	114	85	108

Table 43. Average monthly nitrogen levels, ppm. - Ammonia Nitrogen

Date	Williston	Bismarck	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
August 1952	-	0.00	0.50	0.60	-	0.25
September	0.00	0.05	0.19	0.79	0.20	0.50
October	0.00	0.01	0.10	0.20	0.45	0.15
November	-	0.04	0.50	0.70	0.70	0.44
December	0.00	0.05	0.70	0.7	0.5	0.43
January 1953	0.00	0.03	0.90	0.70	0.5	0.40
February	0.00	0.05	-	-	-	0.70
March	-	-	0.50	0.30	0.15	0.40
April	-	0.50	0.55	0.05	0.55	0.42
May	0.00	0.00	-	0.10	0.05	0.37
June	-	-	0.05	0.05	0.05	0.50
July	-	-	0.00	0.00	0.00	-
August	-	-	0.05	0.05	0.05	-
September	-	-	0.00	0.05	0.05	-
October	-	-	0.00	0.05	0.05	-
November	-	-	0.05	0.05	0.05	-
December	-	-	0.10	0.10	0.05	-
Averages	0.00	0.05	0.250	0.250	0.144	0.411

Table 42. Average monthly nitrogen levels, ppm. - Nitrate Nitrogen

Date	Williston	Bismarck	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
August 1952	-	-	0.20	0.07	0.09	0.07	0.06
September	0.70	0.70	0.09	0.19	0.07	0.07	0.11
October	2.20	1.10	0.09	0.09	0.10	0.11	0.17
November	-	0.00	0.00	0.13	0.10	0.07	0.14
December	0.40	0.00	0.09	0.12	0.15	0.09	0.05
January 1953	0.40	-	-	-	-	-	-
February	0.70	0.40	-	-	-	-	-
March	-	-	-	-	-	-	-
April	-	0.00	-	-	-	-	-
May	0.00	0.00	-	-	-	-	-
June	-	-	-	-	-	-	-
July	-	-	0.10	0.05	0.05	0.10	-
August	-	-	-	0.05	0.05	-	-
September	-	-	-	0.05	0.00	0.10	-
October	-	-	-	0.05	0.17	0.10	-
November	-	-	0.00	0.05	0.00	0.05	-
December	-	-	0.00	0.05	0.10	0.15	-
Averages	0.93	1.58	0.078	0.085	0.104	0.11	0.146

Table 45. Average monthly nitrogen levels, ppm. - Nitrite Nitrogen

Date	Williston	Bismarck	Omaha
August 1952	-	0.00	0.00
September	0.007	0.01	0.00
October	0.0005	0.003	0.00
November	-	0.13	0.00
December	0.007	0.02	0.004
January 1953	0.007	0.005	0.003
February	0.001	0.035	0.004
March	-	-	0.005
April	-	0.035	0.004
May	0.007	0.007	0.006
June	-	-	-
July	-	-	-
August	-	-	-
September	-	-	-
October	-	-	-
November	-	-	-
December	-	-	-
Averages	0.004	0.016	0.002

Table 44. Average monthly nitrogen levels, ppm. - Organic Nitrogen

Date	Pierre	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
August 1952	0.18	0.68	0.17	0.45	0.26
September	1.83	0.85	0.41	0.45	0.65
October	2.13	0.69	0.74	0.70	0.70
November	0.78	0.90	0.94	1.10	1.89
December	0.84	0.78	0.88	0.66	1.08
January 1953	-	-	-	-	-
February	-	-	-	-	-
March	-	-	-	-	-
April	-	-	-	-	-
May	-	-	-	-	-
June	-	-	-	-	-
July	1.09	2.30	1.18	0.84	-
August	-	1.75	0.85	1.75	-
September	-	-	0.79	-	-
October	1.51	1.37	0.41	0.92	-
November	0.05	0.29	0.30	0.35	-
December	0.35	0.75	0.30	0.30	-
Averages	0.751	1.01	0.633	0.752	0.796

Table 5. Summary of Phosphorous Analyses - ppm.

	PO_4 (Available Phosphorous) Individual Analyses		Total Phosphorous as P Monthly Averages				
	Williston	Bismarck	Pierre	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
August 1952	-	0.0	0.0	0.02	0.015	0.015	0.06
September	0.0	<0.02	0.01	0.02	0.024	0.028	0.035
October	0.0	<0.02	0.044	0.024	0.028	0.045	0.012
November	-	-	0.23	0.023	0.17	0.14	0.17
December	0.0	0.02	0.16	0.10	0.07	0.08	0.17
January 1953	0.06	0.04	0.20	0.09	0.12	0.10	0.20
February	0.04	0.10	0.09	0.17	0.15	0.12	0.10
March	-	-	0.10	0.09	0.11	0.15	0.10
April	-	0.55	0.10	0.15	0.08	0.06	0.095
May	0.0	0.22	0.10	0.07	0.08	0.075	0.065
June	-	-	0.07	0.08	0.11	0.06	0.06
July	-	-	0.03	0.01	0.015	0.03	-
August	-	-	-	0.035	0.01	0.03	-
September	-	-	-	-	0.025	-	-
October	-	-	0.32	0.032	0.027	0.015	-
November	-	-	0.025	0.022	0.02	0.025	-
December	-	-	0.05	0.04	0.05	0.05	-
Averages	-	-	0.094	0.061	0.065	0.063	0.097

Table 6a. Summary of Individual Miscellaneous Water Analyses, 1952. - Williston, North Dakota

Date	Turb.	Hardness	Ca	Mg	F	Na	SO_4
9-19-52	280	204	49	21.4	1.2	-	-
10-9-52	300	228	54.3	23.1	1.2	-	-
12-1-52	-	274	69.7	25.4	1.5	-	-
2-2-53	230	264	69.7	23.4	1.3	-	-
5-1-53	420	-	-	-	-	-	-

Table 6b. Summary of Individual Miscellaneous Water Analyses, 1952. - Dickinson, North Dakota

Date	Turb.	Hardness	Ca	Mg	F	Na	SO_4
8-16-52	400	-	-	-	-	-	-
9-10-52	350	212	49	20.1	0.6	-	-
10-17-52	350	202	54.5	23.4	1.2	-	-
11-14-52	400	252	58.5	25.8	1.3	42.2	178.5
12-1-52	420	248	59.5	23.1	1.3	45.0	204.0
1-4-53	25	278	63.5	-	-	-	-
2-19-53	420	268	61.5	24.7	-	43.3	144.0
4-8-53	1,500	208	47.9	21.4	1.5	-	-
5-12-53	1,400	216	49.6	23.8	0.2	17.5	134.2
7-20-53	480	144	33.5	13.6	1.3	7.5	47.0
9-28-53	1,200	216	51.5	17.4	0.2	-	-

Table 6c. Summary of Miscellaneous Miscellaneous Water Analyses, 1952. - Fairfax, South Dakota

Date	Turb.	Hardness	Ca	Mg	SO_4	F
9-25-52	450	136	44	10	0	.7
10-22-52	370	120	42	8.2	14	.8
11-24-52	400	141	51	10	11	-
12-31-52	240	174	60	12	8	.9
1-28-53	40	240	80	17	11	.9
2-25-53	50	154	50	11	11	.5
3-25-53	35	107	34	7.4	17	0.5
4-29-53	4,000	325	78	39	15	.4
6-10-53	250	290	69	34	10	0.5
7-22-53	1,200	274	60	31	11	.4
9-14-53	5,000	218	42	28	14	0.3
10-6-53	550	158	-	-	-	-
10-7-53	500	234	-	-	-	-
11-27-53	125	220	-	-	-	-
11-28-53	150	250	-	-	-	-
12-16-53	150	144	-	-	-	-

Table 6d. Summary of Individual Miscellaneous Water Analyses, 1952. - Chamberlain, South Dakota

Date	Turb.	Hardness	Ca	Mg	SO_4	F	Na	K	SO_4	Cu	Cr
8-18-52	600	181	44	17	11	-	-	-	-	-	-
8-28-52	500	187	47	19	16	0.7	53	3.8	181	0.05	0.00
9-11-52	-	-	-	-	-	-	-	-	-	-	-
9-15-52	440	207	50	20	15	0.7	54	4.3	196	0.03	0.00
9-24-52	-	217	51	22	1	-	-	-	-	-	-
10-8-52	-	225	53	23	11	-	-	-	-	-	-
10-14-52	500	210	49	21	9	-	-	-	-	-	-
10-21-52	460	228	54	23	11	0.6	54	4.1	189	0.03	0.00
10-22-52	-	-	-	-	-	-	-	-	-	-	-
11-5-52	440	222	51	23	11	-	-	-	-	-	-
11-19-52	430	241	61	22	12	-	-	-	-	-	-
11-26-52	420	246	59	23	10	0.7	57	5.2	191	0.00	0.00
12-31-52	35	288	71	27	11	-	-	-	-	-	-
1-19-53	440	325	81	37	10	0.6	81	5.8	225	0.00	0.00
1-27-53	-	-	-	-	-	-	54.6	3.4	183	<0.05	<0.05
1-29-53	50	291	66	34	12	-	-	-	-	-	-
2-2-53	75	342	75	44	10	-	-	-	-	-	-
2-6-53	110	338	82	44	10	-	-	-	-	-	-
2-16-53	90	325	69	44	15	-	-	-	-	-	-
2-23-53	65	338	71	44	12	-	-	-	-	-	-
3-2-53	210	308	69	40	12	-	-	-	-	-	-
3-9-53	120	318	72	37	10	0.5	56.5	3.8	225	<0.05	<0.05
3-10-53	-	-	-	-	-	-	-	-	-	-	-
3-14-53	2,000	273	70	29	15	-	-	-	-	-	-
3-23-53	3,000	294	75	32	12	0.5	58.1	3.8	254	<0.05	<0.05
4-2-53	1,500	239	59	27	10	-	-	-	-	-	-
4-11-53	350	239	59	27	10	-	-	-	-	-	-
4-21-53	1,500	257	61	30	10	0.4	37.2	4.3	244	<0.05	<0.05
4-22-53	-	-	-	-	-	-	-	-	-	-	-
4-27-53	500	241	64	27	12	-	-	-	-	-	-
5-8-53	1,000	230	57	32	12	-	-	-	-	-	-
5-11-53	1,200	230	56	32	12	-	-	-	-	-	-
5-18-53	1,200	230	56	32	12	-	-	-	-	-	-
5-21-53	1,500	254	64	28	0.5	55	3.5	233	<0.05	<0.05	-
6-2-53	2,000	270	69	28	14	-	-	-	-	-	-
7-15-53	6,500	230	59	30	15	-	-	-	-	-	-
7-22-53	6,500	230	59	30	15	0.4	64	4.0	215	<0.05	<0.05
7-29-53	5,500	232	59	29	15	-	-	-	-	-	-
8-7-53	700	196	-	-	-	-	-	-	-	-	-
8-18-53	450	208	-	-	-	-	-	-	-	-	-
9-1-53	500	-	-	-	-	-	-	-	-	-	-
10-13-53	450	238	-	-	-	-	-	-	-	-	-
10-27-53	-	234	-	-	-	-	-	-	-	-	-
11-9-53	-	228	-	-	-	-	-	-	-	-	-
11-16-53	1,150	-	-	-	-	-	-	-	-	-	-
11-17-53	600	234	-	-	-	-	-	-	-	-	-
11-23-53	700	-	-	-	-	-	-	-	-	-	-
11-30-53	550	282	-	-	-	-	-	-	-	-	-
12-7-53	500	-	-	-	-	-	-	-	-	-	-
12-14-53	62	202	-	-	-	-	-	-	-	-	-

Table 6e. Summary of Individual Miscellaneous Water Analyses. ppm. - Below Fort Randall Dam

Date	Turb.	Hardness	Ca	Mg	SiO_2	F
8-19-52	800	183	45	17	10	-
8-27-52	650	187	46	18	10	0.6
9-4-52	1,100	202	50	19	13	-
9-1-52	530	197	49	18	12	-
9-17-52	450	223	51	23	12	-
9-23-52	-	218	47	22	10	0.6
10-1-52	350	225	51	24	14	-
10-8-52	360	229	54	22	10	-
10-15-52	500	211	48	22	11	-
10-21-52	560	206	47	21	8	0.6
10-29-52	370	235	55	24	10	-
11-5-52	300	216	50	22	11	-
11-12-52	400	225	55	21	9	-
11-18-52	370	231	60	20	9	-
11-26-52	290	253	68	21	9	0.8
12-3-52	<30	268	75	25	10	-
12-11-52	45	269	79	22	13	-
12-16-52	40	307	78	27	11	-
12-24-52	55	313	82	26	11	0.8
12-30-52	45	328	83	29	11	-
1-5-53	35	342	77	42	12	-
1-14-53	50	273	66	32	10	-
1-21-53	<30	342	75	44	12	0.4
1-27-53	<30	324	67	45	15	-
2-4-53	35	308	66	41	12	-
2-11-53	40	308	72	37	12	-
2-18-53	<25	291	68	34	10	-
2-25-53	<25	308	80	46	12	0.4
3-4-53	<25	241	71	33	12	-
3-10-53	<25	325	70	43	10	-
3-18-53	1,000	239	63	24	12	-
3-25-53	3,000	271	73	29	10	0.5
4-1-53	150	222	58	24	10	-
4-8-53	130	257	66	27	18	-
4-15-53	150	273	70	32	10	-
4-22-53	<30	273	62	36	10	0.4
4-29-53	50	325	68	44	10	-
5-6-53	2,000	257	70	23	10	-
5-13-53	65	239	54	27	20	-
5-20-53	<30	273	82	20	12	-
5-27-53	<30	257	65	27	18	0.3
6-3-53	<30	340	62	44	16	-
6-10-53	60	261	57	29	15	-
6-16-53	80	275	64	28	20	-
6-24-53	575	228	52	23	12	0.3
7-8-53	30	159	-	-	-	-
7-15-53	35	154	-	-	-	-
8-4-53	30	-	-	-	-	-
8-12-53	27	176	-	-	-	-
8-18-53	47	188	-	-	-	-
9-1-53	30	-	-	-	-	-
9-8-53	<25	230	-	-	-	-
9-15-53	30	-	-	-	-	-
9-23-53	30	230	-	-	-	-
9-27-53	<25	-	-	-	-	-
10-7-53	<25	232	-	-	-	-
10-1-53	<25	-	-	-	-	-
10-21-53	<25	237	-	-	-	-
10-29-53	<25	234	-	-	-	-
11-4-53	25	234	-	-	-	-
11-16-53	-	234	-	-	-	-
11-17-53	<25	-	-	-	-	-
11-23-53	<25	-	-	-	-	-
11-30-53	<25	244	-	-	-	-
12-7-53	<24	-	-	-	-	-
12-14-53	<25	248	-	-	-	-
12-21-53	<25	-	-	-	-	-
12-28-53	<25	-	-	-	-	-

Table 6f. Summary of Individual Miscellaneous Water Analyses. ppm. - Yankton, South Dakota

Date	Turb.	Hardness	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-20-52	650	175	43	16	12	-	-	-	-	-	-
8-27-52	600	153	34	17	47	0.7	52	4.1	179	0.05	0.0
9-3-52	580	193	49	17	8	-	-	-	-	-	-
9-10-52	650	175	41	18	22	-	-	-	-	-	-
9-17-52	450	207	51	18	27	31	-	-	-	-	-
9-24-52	500	207	51	19	14	0.6	52	3.9	178	0.03	0.0
10-1-52	480	220	54	22	13	-	-	-	-	-	-
10-8-52	420	224	53	22	12	-	-	-	-	-	-
10-15-52	500	222	51	23	13	-	-	-	-	-	-
10-21-52	500	225	53	23	13	0.7	53	4.3	179	0.03	0.0
10-29-52	500	209	49	25	14	-	-	-	-	-	-
11-5-52	-	225	51	24	12	-	-	-	-	-	-
11-12-52	480	218	54	20	11	-	-	-	-	-	-
11-18-52	-	232	59	21	13	-	-	-	-	-	-
11-26-52	320	235	62	19	12	0.7	54	4.9	193	0.0	0.0
12-3-52	<30	285	72	26	14	-	-	-	-	-	-
12-10-52	75	258	63	25	18	-	-	-	-	-	-
12-16-52	40	251	64	22	17	-	-	-	-	-	-
12-24-52	45	282	71	26	21	0.6	67	6.0	234	0.0	0.0
12-31-52	45	338	84	31	14	-	-	-	-	-	-
1-7-53	45	345	81	35	35	-	-	-	-	-	-
1-14-53	75	291	68	32	18	-	-	-	-	-	-
1-22-53	45	342	58	56	15	0.5	59.8	3.1	212	<0.05	<0.05
1-27-53	65	273	54	40	25	-	-	-	-	-	-
2-4-53	80	308	63	43	35	-	-	-	-	-	-
2-11-53	60	308	72	37	17	-	-	-	-	-	-
2-18-53	55	273	53	42	20	-	-	-	-	-	-
2-25-53	35	308	61	45	23	0.5	54.4	3.8	232	<0.05	<0.05
3-4-53	35	273	62	34	15	-	-	-	-	-	-
3-10-53	90	291	70	33	15	-	-	-	-	-	-
3-18-53	3,000	222	63	19	13	-	-	-	-	-	-
3-25-53	3,000	273	70	29	14	0.4	53.9	4.6	254	<0.05	<0.05
4-1-53	460	265	64	28	10	-	-	-	-	-	-
4-8-53	350	282	64	30	15	-	-	-	-	-	-
4-15-53	300	316	69	33	12	-	-	-	-	-	-
4-22-53	85	319	66	36	18	0.3	56.4	4.2	221	<0.05	<0.05
4-29-53	180	291	69	34	10	-	-	-	-	-	-
5-6-53	5,000	308	76	34	10	-	-	-	-	-	-
5-13-53	400	239	63	24	15	-	-	-	-	-	-
5-20-53	150	257	66	25	10	-	-	-	-	-	-
5-27-53	55	273	69	32	20	0.5	60.9	4.8	241	<0.05	<0.05
6-3-53	120	308	63	43	25	-	-	-	-	-	-
6-10-53	200	304	68	33	10	-	-	-	-	-	-
6-17-53	210	305	64	36	15	0.5	66	6.3	224	<0.05	<0.05
6-24-53	2,500	232	47	28	12	-	-	-	-	-	-
7-21-53	120	164	-	-	-	-	-	-	-	-	-
8-4-53	190	-	-	-	-	-	-	-	-	-	-
8-18-53	95	184	-	-	-	-	-	-	-	-	-
9-1-53	100	-	-	-	-	-	-	-	-	-	-
9-9-53	90	-	-	-	-	-	-	-	-	-	-
9-15-53	105	-	-	-	-	-	-	-	-	-	-
9-29-53	100	-	-	-	-	-	-	-	-	-	-
10-7-53	150	-	-	-	-	-	-	-	-	-	-
10-13-53	45	-	-	-	-	-	-	-	-	-	-
10-21-53	95	-	-	-	-	-	-	-	-	-	-
10-27-53	-	234	-	-	-	-	-	-	-	-	-
11-3-53	-	246	-	-	-	-	-	-	-	-	-
11-29-53	95	-	-	-	-	-	-	-	-	-	-
11-2-53	-	206	-	-	-	-	-	-	-	-	-
11-4-53	110	-	-	-	-	-	-	-	-	-	-
11-17-53	180	-	-	-	-	-	-	-	-	-	-
11-23-53	105	-	-	-	-	-	-	-	-	-	-
11-30-53	122	246	-	-	-	-	-	-	-	-	-
12-7-53	115	-	-	-	-	-	-	-	-	-	-
12-14-53	100	250	-	-	-	-	-	-	-	-	-
12-15-53	87	-	-	-	-	-	-	-	-	-	-
12-21-53	42	-	-	-	-	-	-	-	-	-	-
12-28-53	36	-	-	-	-	-	-	-	-	-	-

Table 6g. Summary of Individual Miscellaneous Water Analyses. ppm. - Omaha, Nebraska

Date	Turb.	Hardness	Ca	Mg	SiO_2	F
8-21-52	700	189	48	17	11	0.6
9-9-52	650	210	47	23	14	-
9-25-52	500	225	54	22	12	0.5
10-16-52	600	232	56	23	12	0.6
11-29-52	650	234	56	23	12	-
12-13-52	625	245	64	21	11	-
11-29-52	330	260	68	22	10	0.8
12-8-52	110	296	79	24	12	-
12-22-52	65	322	81	29	17	0.7
12-31-52	45	339	85	30	17	-
1-16-53	75	325	64	47	35	0.6
2-2-53	60	342	72	47	28	-
2-6-53	80	345	79	37	12	-
2-23-53	95	325	76	39	22	0.6
3-12-53	1,000	308	77	33	12	-
3-26-53	3,000	291	74	31	10	0.3
4-10-53	500	273	68	30	12	-
4-23-53	270	308	75	34	15	0.5
5-11-53	5,000	291	74	31	12	-
5-30-53	300	273	74	26	12	0.4
6-13-53	1,500	275	57	32	12	0.3

Table 7. Phytoplankton Group Names and Species Included Under Each

Group Name	Species Included
Blue-Green Algae:	
Chroococcus	Chroococcus* spp.
Gomphosphaeria-Coelosphaerium gr.	Coelosphaerium Kuetzingianum Naegeli*
	Coelosphaerium dubium Grunow*
	Gomphosphaeria aponina Kuetzing*
Aphanizomenon	Aphanizomenon flos-aquae (L) Ralfs*
Oscillatoria gr.	Oscillatoria spp.*
	Phormidium spp.
Nostoc gr.	Nostoc spp.
	Anabaena spp*
Dactylococcopsis	D. acicularis Lemmermann*
Lyngbya	Lyngbya spp*
	Lyngbya contorta Lem.*
Spirulina	S. major Kuetzing*
	S. princeps (W. & G. S. West)*
Merismopedia	M. elegans A. Braun*
Diatoms:	
Melosira (a)	M. granulata var. angustissima Muell.*
Melosira (b)	M. granulata (Ehr.) Ralfs*
Cyclotella (a)	C. glomerata Bachmann*
Cyclotella-Stephanodiscus gr.	Stephanodiscus astraea (Ehr.) Grun.*
	S. astraea var. minutula (Kuetz) Grun* (most numerous of this group)
	S. Hantzschii Grun.*
	S. subsalsus (A.Cl.) Huet.*
	S. Subtilis (Fricke) Huet.*
	Cyclotella Bodanica Eulenst.*
	Cyclotella sp..*
Rhizosolenia gr.	Rhizosolenia longiseta Zach.
	Rhizosolenia sp.
Bacillaria	Bacillaria paxillifera Ehr.
Synedra gr.	S. delicatissima W. Smith
	S. filiformis var. exilis (Kuetz.) Hust.
	S. ulna (Nitzsch) Ehr.
	S. ulna var. contracta Oestrup
	S. vaucheriae Kuetz.
Tabellaria	T. fenestrata (Lyngb.) Kuetz.*
Fragilaria crotonensis	F. crotonensis Kitton*
Fragilaria gr.	F. capucina Desm.
	F. construens (Ehr.) Grun
	F. construens var. venter (Ehr.) Grun

Group Name	Species Included
Fragilaria gr. (contd.)	F. construens var. binodis (Ehr.) Grun.
	F. Harrisonii var. Subsalsa Grun.
	Opephora martyi Heribaud
Asterionella	A. formosa Hassall*
Centronella	Centronella reichelti Voigt
Synedra gr.	Synedra ulna (Nitzsch.) Ehr.
	S. ulna var. contracta (Kuetz.) Hust.
	S. affinis Kuetz.
	S. affinis var. fasciculata (Kuetz.) Grun
	S. amphicephala Kuetz.
	S. rumpens Kuetz.
Cerataulus	Cerataulus scus Kuetz.
Rhoicosphenia	R. curvata (Kuetz.) Grun.
Cymatopleura	Pleurosigma delicatulum W. Smith
	Cymatopleura acuminata (Kuetz.) Rabh.
Surirella gr.	Surirella var. constricta var. capitellata Grun
	Surirella ovata Kuetz.
	Surirella ovata var. pinnata W. Smith
	S. robusta Ehr.
	S. splendida (Ehr.) Kuetz.
	S. tenera Greg.
	S. tenera var. nervosa Grun.
	S. tenuissima W. Smith
	Campylodiscus clypeus Ehr.
	Campylodiscus hibernicus Ehr.
	Campylodiscus noricus var. Ralfsii W. Smith
	Campylodiscus thuretii Breb.
Amphora	Amphora ovalis (Kuetz.)
	Amphora ovalis var. pediculus (Kuetz.) V.H.
	Amphora veneta Kuetz.
Cymbella	Cymbella cistula (Hemprich) Von Heurck
	C. cymbiformis Kuetz.
	C. delicatula Kuetz.
	C. turgida (Gregory) Cleve
Gomphonema gr.	Gomphonema olivaceum (Lyng.) Kuetz.
	G. olivaceum var. insigne (Grev.) Cleve
	G. acuminatum var. coronatum (Ehr.) Grun
Epithemia	Epithemia argus var. alpestris (Hust.)
Rhopalodia	Rhopalodia gibba (Ehr.) O. Muell.
Nitzschia gr.	Nitzschia closterium W. Smith
	Nitzschia longissima (Ehr.) Ralfs
	Nitzschia recta Hantzsch
	N. sigma (Kuetz.) W. Smith

Group Name	Species Included
Nitzschia gr. (contd.)	N. sigmoidea (Ehr.) W. Smith
	N. vermicularis (Kuetz.) Grun
	N. capitellata Hust
	N. commutata Grun
	N. tryblionella Hantzsch
	N. acuta Hantzsch.
Cymatopleura	Cymatopleura solea (Brebisson) W. Smith
Surirella	Surirella ovata Kuetz.
	S. robusta Ehr.
Green Algae:	
Volvocales:	
Chlamydomonas gr.	Chlamydomonas sp..*
	Coccomonas sp.*
Pandorina	P. morum (Muell.) Bory*
Eudorina	E. elegans Ehr.*
Pleodorina	P. californica Shaw*
	P. illinoisensis Kofoid*
Tetrasporales:	
Dictyosphaerium	D. pulchellum Wood*
	D. ehrenbergianum Nag.*
Sphaerocystis	S. Schroeteri Chodat*
Gloeocystis	G. ampla (Kuetz.) Lagerheim*
	G. major Gerneck*
Chlorococcales:	
Actinastrum Hantzschii	A. Hantzschii Lagerheim*
Ankistrodesmus falcatus	A. falcatus (Corda) Ralfs*
	A. falcatus var. acicularis (A. Braun) Lemm.*
Closteriopsis longissima	C. longissima Lemmermann*
Crucigenia	C. quadrata Morren*
	C. rectangularis (A. Braun) Gay*
	C. tetrapedia (Kirch.) W. & G. S. West*
Dictyosphaerium	D. ehrenbergianum Nag.*
	D. pulchellum Wood*
Elakatothrix	E. gelatinosa Wille*
Golenkinia	G. radiata Chodat*
Kirchneriella	K. lunaris (Kirch.) Moebius*
	K. obesa (West) West & West*
Lagerheimia	L. genevensis (Chodat) Chodat*
Micractinium	M. pusillum Fresenius*
Monoraphidium	M. arcuatum (Korsikov) Hind.*
	M. contortum (Thuret) Kom.-Legn.*
	M. griffithii (Berkeley) Kom.-Legn.*
Nephrocytium	N. agardhianum Nageli*
Oocystis	O. borgei Snow*
	O. lacustris Chodat*
	O. parva West & West*
	O. pusilla Hansgirg*
Pediastrum	P. boryanum (Turp.) Menegh.*
	P. duplex Meyen*
	P. duplex var. clathratum (A. Braun) Lagerh.*
	P. duplex var. gracillimum West & West*
	P. duplex var. reticulatum Lagerheim*
	P. simplex var. echinatum Reinsch*
Quadrigula	Q. closterioides (Bohlin) Printz*
Scenedesmus	S. abundans (Kirch.) Chodat*
	S. acuminatus (Lagerh.) Chodat*
	S. arcuatus (Lemm.) Lemmermann*
	S. bijugatus (Kuetz.) Lagerheim*
	S. bijugatus var. alternans (Reinsch) Hansgirg*
	S. bijugatus var. flexuosus Hansgirg*
	S. bijugatus var. graevenitzii (Bern.) Chodat*
	S. bijugatus var. irregularis (G.M. Smith) Hansgirg*
	S. bijugatus var. linearis Hansgirg*
	S. bijugatus var. planctonicus Korshikov*
	S. bijugatus var. tenuispina (Hansgirg) Hansgirg*
	S. brasiliensis Bohlin*
	S. dimorphus (Turp.) Kuetz.*
	S. denticulatus Lagerheim*
	S. ecornis (Ralfs) Chodat*
	S. longus Meyen*
	S. obliquus (Turp.) Kuetz.*
	S. opoliensis P. Richter*
	S. quadricauda (Turp.) de Brebisson*
	S. serratus (Corda) Bohlin*
	S. spinosus Chodat*
Selenastrum	S. bibraianum Reinsch*
	S. gracile Reinsch*
Tetraedron	T. caudatum (Corda) Hansgirg*
	T. minimum (A. Braun) Hansgirg*
	T. muticum (A. Braun) Hansgirg*
	T. trigonum (Naeg.) Hansgirg*
Tetrastrum	T. staurogeniaeforme (Schroed.) Lemmermann*
Treubaria	T. setigerum (Archer) Bernard*
	T. triappendiculata Bernard*
Westella	W. botryoides (W. West) De Wildeman*
Other Forms	
Actinastrum gelidum Prescott*	
Ankistrodesmus angustus Bernard*	
Ankistrodesmus falcatus var. mirabilis (Schmidle) Lemm.*	
Ankistrodesmus spiralis (Turner) Lemm.*	
Botryococcus braunii Kuetz.*	
Chlorella vulgaris Beij.*	
Closteriopsis acicularis Chodat*	
Coelastrum astroideum De Notaris*	
Coelastrum microporum Naegeli*	
Coelastrum proboscideum Bohlin*	
Crucigenia fenestrata (Schmidle) Schmidle*	
Crucigenia irregularis Wille*	
Crucigenia lauterbornei (Schmidle) Schmidle*	
Crucigenia quadrata Morren*	
Crucigenia rectangularis (A. Braun) Gay*	
Crucigenia tetrapedia (Kirch.) W. & G. S. West*	
Dictyosphaerium ehrenbergianum Nag.*	
Dictyosphaerium pulchellum Wood*	
Elakatothrix gelatinosa Wille*	
Gloeocystis gigas (Kuetz.) Lagerheim*	
Gloeocystis major Gerneck*	
Golenkinia radiata Chodat*	
Kirchneriella contorta (Schmidle) Bohlin*	
Kirchneriella lunaris (Kirch.) Moebius*	
Kirchneriella obesa (West) West & West*	
Lagerheimia genevensis (Chodat) Chodat*	
Micractinium pusillum Fresenius*	
Nephrocytium agardhianum Nageli*	
Oocystis borgei Snow*	
Oocystis lacustris Chodat*	
Oocystis parva West & West*	
Oocystis pusilla Hansgirg*	
Quadrigula closterioides (Bohlin) Printz*	
Quadrigula lacustris (Chodat) G.M. Smith*	
Scenedesmus abundans (Kirch.) Chodat*	
Scenedesmus acuminatus (Lagerh.) Chodat*	
Scenedesmus arcuatus (Lemm.) Lemmermann*	
Scenedesmus bijugatus (Kuetz.) Lagerheim*	
Scenedesmus bijugatus var. alternans (Reinsch) Hansgirg*	
Scenedesmus bijugatus var. flexuosus Hansgirg*	
Scenedesmus bijugatus var. graevenitzii (Bern.) Chodat*	
Scenedesmus bijugatus var. irregularis (G.M. Smith) Hansgirg*	
Scenedesmus bijugatus var. linearis Hansgirg*	
Scenedesmus bijugatus var. planctonicus Korshikov*	
Scenedesmus bijugatus var. tenuispina (Hansgirg) Hansgirg*	
Scenedesmus brasiliensis Bohlin*	
Scenedesmus dimorphus (Turp.) Kuetz.*	
Scenedesmus denticulatus Lagerheim*	
Scenedesmus ecornis (Ralfs) Chodat*	
Scenedesmus longus Meyen*	
Scenedesmus obliquus (Turp.) Kuetz.*	
Scenedesmus opoliensis P. Richter*	
Scenedesmus quadricauda (Turp.) de Brebisson*	
Scenedesmus serratus (Corda) Bohlin*	
Scenedesmus spinosus Chodat*	
Selenastrum bibraianum Reinsch*	
Selenastrum gracile Reinsch*	
Tetraedron caudatum (Corda) Hansgirg*	
Tetraedron minimum (A. Braun) Hansgirg*	
Tetraedron muticum (A. Braun) Hansgirg*	
Tetraedron trigonum (Naeg.) Hansgirg*	
Tetrastrum staurogeniaeforme (Schroed.) Lemmermann*	
Treubaria setigerum (Archer)*	
Treubaria triappendiculata Bernard*	
Westella botryoides (W. West) De Wildeman*	
Ulothrix sp.	
Oocystis sp.*	
Tetraedron sp.*	
Lagerheimia genevensis (Chodat) Chodat*	
Coelastrum sibiricum Archer*	
Coelastrum proboscideum Bohlin*	
Chrysophyceae:	
Dinobryon	D. sertularia Ehr.*
Dinoflagellates:	
Ceratium	C. hirundinella (O.F. Muell.) Bajardia*
Euglenophyceae:	
Trachelomonas sp.	T. hispida (Perty)*
	T. volvocina Ehr.*
	Trachelomonas urceolata Stokes*
	Euglena oxyuris Schr.*
	Euglena spirogyra Ehr.*
	Phacus sp.*
Diatoms (contd):	
Coscinodiscus	Coscinodiscus pelagicus Ehr.

* Taxa [illegible]

Table 8 Most numerous organisms at each station in descending order for each month

	Williston	Bismarck	Pierre	Chamberlain	Ft. Randall	Yankton	Omaha
August 1952	-	Gompho-Coelo. Frag. crotenensis Synedra gr. Melosira (a)	Melosira (a) Syneira gr.	Cyclo.-Stephano gr. Melosira (a) Frag. crotenensis Synedra gr.	Cyclo.-Stephano. gr. Frag. crotenensis	Cyclo.-Stephano. gr. Frag. crotenensis	Chlamydomonas gr.
September	Synedra Gompho-Coelo. Frag. crotenensis	-	Melosira (a) Fragillaria crotenensis	Melosira (a) Cyclotella-Stephano. gr. Fragillaria crotenensis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Gompho.-Coelo. gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.
October	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. Synedra gr.	Gompho.-Coelo. Aphanizomenon	Cyclo.-Stephano. gr. Aphanizomenon Asterionella	Melosira (a) Cyclo.-Stephano. gr. Synedra gr.	Nitzschia gr. Synedra gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.
November	-	Synedra gr. Cyclo.-Stephano. Navicula gr.	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Synedra. Navicula gr.	Cyclo.-Stephano. gr. Navicula gr. Nitzschia gr.	Cyclo.-Stephano. gr. Navicula gr. Nitzschia gr.
December	-	Gompho-Coelo. Chlamydomonas	Synedra gr.	Synedra gr. Chlamydomonas	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Synedra gr.	Cyclotella (a) Chlamydomonas gr. Synedra gr.
January 1953	-	-	Synedra gr. Chlamydomonas	Chlamydomonas gr. Synedra gr.	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Synedra gr. Navicula gr.	Chlamydomonas gr. Synedra gr. Euglena spp.
February	Synedra gr.	Synedra gr.	Gloeocystis Chlamydomonas	Chlamydomonas gr. Synedra gr.	Chlamydomonas gr. Synedra gr. Gloeocystis	Chlamydomonas gr. Synedra gr. Nitzschia gr.	Nitzschia gr. Synedra gr. Chlamydomonas gr.
March	-	No dominant organism	Nitzschia gr. Navicula gr.	Nitzschia gr. Synedra gr.	Nitzschia gr.	Chlamydomonas gr. Navicula gr. Nitzschia gr.	Nitzschia gr. Navicula gr.
April	-	-	Asterionella Synedra gr. Nitzschia gr.	Asterionella Synedra gr. Chlamydomonas	Nitzschia gr. Chlamydomonas Synedra gr.	Navicula gr. Nitzschia gr. Synedra gr.	Rhizosolenia gr. Synedra gr. Asterionella
May	Chlamydomonas gr. Cyclotella (a) Asterionella	Asterionella Synedra gr.	Asterionella Navicula gr. Diatoma elongatum	Asterionella Navicula gr. Synedra gr.	Asterionella Cyclotella (a) Cyclo.-Stephano. gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.
June	-	-	-	Nitzschia gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Nitzschia gr. Synedra gr.	Cyclotella-Stephano.gr. Asterionella Diatoma elongatum	Cyclo.-Stephano. gr. Navicula gr.
July	-	Trachelomonas	Cyclotella-Stephano.	Cyclo.-Stephano. gr.	Cyclo.-Stephano.gr. Chlamydomonas gr.	Cyclotella-Stephano gr. Navicula gr.	-
August	-	Chlamydomonas gr.	-	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano.gr.	-
September	-	-	-	Melosira (a) Synedra gr. Nitzschia gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano. gr.	-
October	-	-	Synedra gr.	Navicula gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Melosira (a)	Melosira (a) Navicula gr. Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano gr. Navicula gr.
November	-	-	Nitzschia gr.	Cyclo.-Stephano. gr. Synedra gr. Nitzschia gr.	Cyclo.-Stephano. gr. Chlamydomonas gr. Navicula gr.	Navicula gr. Melosira (a) Nitzschia gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Navicula gr.
December	-	-	Navicula gr. Chlamydomonas gr.	Cyclo.-Stephano. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella	Asterionella Cyclo.-Stephano gr. Chlamydomonas gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Cyclotella (a)

Table 9. Individual Plankton analyses - Williston, North Dakota

	9-10-52	10-9-52	2-3-53	5-5-53
1. Chroococcus				2
2. Gomphosphaeria-Coelosphaerium gr.	11	1		
3. Oscillatoria gr.	2	1		
4. Nostoc gr.	1			
5. Anabaenopsis	1	1		
6. Melosira (a)	9	2		
7. Cyclotella-Stephanodiscus gr.	1	12		
8. Cyclotella (a)				50
9. Rhizosolenia gr.	4	2	2	5
10. Fragilaria crotonensis	10			
11. Diatoma vulgare				
12. Asterionella		3	1	26
13. Synedra gr.	14	9	4	2
14. Cyrtolepa gr.	3	3		
15. Navicula gr.		4	1	3
16. Cymbella				2
17. Nitzschia gr.	5			5
18. Surirella				2
19. Chlamydomonas gr.			2	80
20. Glenodinium				3
21. Pediastrum duplex	2			
22. Scenedesmus quadricauda		1		
23. Actinastrum		1		
24. Ankistrodesmus	1			1
25. Ankistrodesmus				3
26. Euglena spp.			1	7
27. Trachelomonas armaeiata	1			
28. Trachelomonas sp.				1
Total No. per ml.	66	49	11	191

Table 10. Individual Plankton analyses - Bismarck, North Dakota

	8-16-52	9-12-52	10-16-52	11-14-52	12-19-52	2-17-53	3-31-53	5-12-53	7-[illegible]-53	8-25-53
1. Gomphosphaeria-Coelosphaerium gr.	28	Sample		4	286					
2. Oscillatoria gr.		not		1						
3. Anabaenopsis	4	preserved	1							2
4. Melosira (a)	11		3	4					1	
5. Melosira (b)	1		2							
6. Cyclotella-Stephanodiscus gr.	5		11	9				2		
7. Rhizosolenia gr.	2		2	4				4		
8. Fragilaria crotonensis	25		1					4		
9. Diatoma vulgare				1						
10. Diatoma elongatum								2		
11. Asterionella	1		1	1				56		
12. Synedra gr.	14		6	10	2	3		12	2	
13. Cyrtolepa gr.				1				4		
14. Navicula gr.			3	8	1	2	2	2		1
15. Pinnularia sp.			1							
16. Cymbella	2		2	3				2		
17. Nitzschia gr.			2			2	2		1	
18. Surirella							1		1	
19. Chlamydomonas gr.					5	2	2	4		4
20. Tetraspora sp.									1	
21. Pediastrum duplex	7		1	1						
22. Scenedesmus bijuga										1
23. Actinastrum									1	
24. Ankrodesmus	4									
25. Ankistrodesmus								2		
26. Dictyosphaerium					3					
27. Closterium sp.								2		
28. Euglena spp.						2	2			
29. Trachelomonas armaeiata	1									
30. Trachelomonas spp.				2				4	2	1
Total No. per ml.	95		37	48	298	11	9	100	10	10

Table 9c. Individual Plankton Analyses - Pierre, South Dakota

	8-25-52	9-22-52	10-20-52	11-21-52	12-22-52	1-21-53	2-23-53	3-26-53	4-20-53	5-27-53	6-19-53	7-24-53	10-6-53	10-26-53	11-29-53	12-16-53
1. Chroococcus gr.									2		Less than					
2. Gomphosphaeria-Coelosphaerium gr.			8								4					
3. Oscillatoria gr.											organisms	1		2	1	
4. Aphanizomenon	2	1	4								per ml.			1		
5. Melosira (a)	14	9				1						2	1	1	1	
6. Melosira (b)	2															
7. Cyclotella-Stephanodiscus gr.	4	1	3	11						10		17	1		4	
8. Rhizosolenia gr.	4	1		1						20						
9. Fragilaria crotonensis	5	5		1					2							
10. Diatoma vulgare									2							
11. Diatoma elongatum									2	50						
12. Asterionella	1	1	3		2	1			45	400						
13. Synedra gr.	8	6	2	10	17	7	2		20	50		4	2	3	1	
14. Gymnodinium gr.	1	1							1							
15. Coccomonas									1							
16. Navicula gr.	2		3	2				6	14	90		1		4	1	1
17. Cymbella				2					3	20				1		
18. Amphora										10						
19. Cystopleura			1												1	
20. Rhopalodia																
21. Nitzschia gr.	1	3	6		2			10	14	90		1	1	1	3	
22. Surirella	1								2	10						
23. Chlamydomonas gr.	1			1	1	4	3		3			2	3			2
24. Glenocystis							7		5				1			1
25. Pediastrum duplex	1		1									1	1			
26. Scenedesmus bijuga													1			
27. Scenedesmus quadricauda		1														
28. Ankistrodesmus					1											
29. Ankyra	2															
30. Closteriopsis	1		2				1									
31. Actinastrum	3															
32. Euglena sp.						2		1	2			1	1			
33. Trachelomonas sp.		1		1			1	2							1	
Number per ml.	21.5	1.6	7.0	1.75	3.3	2.1	0.9	6.0	22.66	64.5		5.0	0.25	4.9	1.2	0.66

Table 91[1] Individual floristic analyses - Chamberlain, Arctic Canada

	8-10-52	8-28-52	9-15-52	9-29-52	10-14-52	10-30-52	11-3-52	11-19-52	11-26-52	12-5-52	12-16-52	1-19-53	1-28-53	2-2-53	2-9-53
1. Chroococcus gr.												1		1	
2. Gomphosphaeria-Coelosphaerium gr.	1		1							2					
3. Merismopedia		1													
4. Oscillatoria gr.		1	1				1	1							
5. Lyngbya															
6. Anabaenopsis	1	2	4	5	5	2	1								
7. Nostoc gr.	3			1		1									
8. Navicula (a)	1	29	15	11	1			1	1			1			
9. Navicula (b)					2	1									
10. Cyclotella-Stephanodiscus gr.	13	30	13	4	2	10	17	6	19	4	2	1			
11. Cyclotella (a)										6					
12. Melosira gr.			1	2		1			2		1		1	1	
13. Bidulphia															
14. Fragilaria construens	1	7	6	3	2	2	1	2			1				2
15. Diatoma vulgare					1			2	1						
16. Diatoma elongatum															
17. Asterionella formosa		4			2	1	1	1	4		2	1		1	
18. Synedra gr.	2	9	4	1	8		1	21	15	8	3	10	6	5	3
19. Cocconeis															
20. Gyrosigma gr.		1	1		1		1								
21. Navicula gr.		3	2	3	4	1	2	11	9	2				1	
22. Cymbella						1		1	1	1					
23. Amphora															
24. Amphiprora gr.															
25. Epithemia								1							
26. Rhoicosphenia						1									
27. Tabellaria gr.	2	3		3	2		1	6	2						3
28. Surirella	1		1		4	1	1								
29. Chlamydomonas gr.		1				2				3	3	4	10	14	7
30. Dinobryon															3
31. Peridinium bailey	4	3	2												
32. Peridinium borgeanum					1										
33. Gymnodinium bilunae															
34. Gymnodinium limnythus					1					1					
35. Gymnodinium pulchrissimum		1													
36. Actinastrum		5								2					
37. Dictyosphaerium	2	2	1	1											
38. Ankistrodesmus									1	2	1	1			
39. Botryococcus					2				1						
40. Lagerheimia									1						
41. Oocystis		1													
42. Ankistrodesmus															
43. Cosmarium															
44. Euglena acus			1		1										
45. Euglena pustifera			1												
46. Euglena spp.		2						1	1	4		2	2	3	2
47. Trachelomonas crenulata	1	2	1												
48. Trachelomonas sp.	1		2	1				1		4		1			
49. Ceratium															
Y units per ml.	30.41	45.0	22.21	15.9	11.2	5.9	6.0	10.2	6.2	2.75	1.2	2.5	0.875	1.15	3.85

Table 16[2] Qualitative floristic analyses - Chamberlain, Ault Dyats (Cont.)

	2-18-53	3-03-53	3-31-53	3-9-53	3-16-53	3-23-53	4-2-53	4-11-53	4-13-53	4-27-53	5-8-53	5-11-53	5-18-53	6-3-53	6-9-53	6-15-53
1. Chroococcus gr.								1								Less
2. Gomphosphaeria-Coelosphaerium gr.																than
3. Dactylococcopsis																4
4. Oscillatoria gr.													2			Organisms
5. Lyngbya													4	5		per ml.
6. Chroococcus																
7. Nostoc gr.												2		1		
8. Melosira (a)															10	
9. Melosira (b)																
10. Cyclotella-Stephanodiscus gr.				1				1		1		2	6	15	20	
11. Cyclotella (s)														10		
12. Meridion gr.			1									4	18			
13. Bitbuchia																
14. Fragilaria crotonensis				2												
15. Diatoma vulgare			1	1				1					6	5		
16. Diatoma elongatum										6			12	5		
17. Asterionella formosa				1				3		58	21	56	126	5	20	
18. Synedra gr.	2	6	5	6			2	3		11	10		46	190	40	
19. Tabellaria																
20. Synedra gr.			2				1						2			
21. Navicula gr.	4	1		2	1		1	5		1	48	2	28	30	70	
22. Cymbella								2					12	5	20	
23. Amphora			1													
24. Gomphonema gr.				1			1									
25. Epithemia																
26. Rhopalodia																
27. Nitzschia gr.	1		6	7		2	6	9	2	7	20	6	24	235	40	
28. Surirella		1			1			4	2	2	10		8			
29. Chlamydomonas gr.			2	1	1	8	1	1	2	42		11	16	5		
30. Gloeocystis	2		4										6			
31. Pediastrum boryanum																
32. Pediastrum duplex																
33. Scenedesmus bijuga																
34. Scenedesmus dimorphus																
35. Scenedesmus quadricauda																
36. Actinastrum														25		
37. Closteriopsis													2			
38. Ankistrodesmus														10		
39. Staurastrum		*												10		
40. Lagerheimia																
41. Ankyra																
42. Staurastrum																
43. Crucigenia								4								
44. Euglena acus								1								
45. Euglena rostifera																
46. Euglena sp.	1	2	2	1	2		1	1	6	3		4	2			
47. Trachelomonas armeniata																
48. Trachelomonas sp.		1	2			4		1	2			2	6			
49. Ceratium																
N units per ml.	1.4	2.01	6.5	4.1	5.4	1.06	2.04	7.2	1.9	19.15	16.6	11.4	61.12	176.5	40.6	

Table 9a[3] Subtidal Plankton analyses - Chamberlain, South Dakota (Cont.)

	6-22-53	6-29-53	7-21-53	8-18-53	9-15-53	10-13-53	11-3-53	11-17-53	11-23-53	11-30-53	12-7-53	12-14-53	12-21-53	12-28-53
1. Chroococcus gr.			2											
2. Gomphosphaeria-Coelosphaerium gr			1											
3. Dactylococcopsis				1										
4. Oscillatoria gr.	6			1										
5. Lyngbya														
6. Aphanizomenon				9	1			2	1					
7. Rhaphidium gr.														
8. Melosira (a)			3	44	10	1	1	1	1	3	1			1
9. Melosira (b)			2					1	1	1	1			
10. Cyclotella-Stephanodiscus gr.	2	4	202	13	3	4	4	3	6	14	10	3		
11. Cyclotella (a)														
12. Rhizosolenia gr.				1	1									
13. Biddulphia														
14. Fragilaria crotonensis			1	2	1									
15. Diatoma vulgare											3			
16. Diatoma elongatum														
17. Asterionella formosa				1				1		1	1			1
18. Synedra gr.	1		1		8	1	2	5		2	2	1		2
19. Cocconeis														
20. Gyrosigma gr.	2				1					1				
21. Navicula gr.	4	2	1	9	6	5	5	3	3	3	7	2	3	1
22. Cymbella		2								2				
23. Amphora														
24. Epithemia gr.										1				
25. Cymatopleura														
26. Rhoicosphenia		2												
27. Nitzschia gr.				5	7	3	6	3	3	1	6			
28. Surirella			1			1								
29. Chlamydomonas gr.	2		2	2		1		2	1	2	1	4	10	11
30. Oocystis		2	2								1		1	2
31. Pediastrum duplex														
32. Pediastrum boryanum														
33. Scenedesmus bijuga			3	1	2									
34. Scenedesmus dimorphus												1		
35. Scenedesmus quadricauda														
36. Actinastrum			4											
37. Closteriopsis			3	3		1					1			
38. Ankistrodesmus														
39. Sphaerella													1	
40. Lagerheimia														
41. Coelastrum														
42. Staurastrum														
43. Cosmarium														
44. Euglena acus			2											
45. Euglena rostifera														
46. Euglena spp.			1	2							2	1		
47. Trachelomonas armaleta			2											
48. Trachelomonas spp.			5		1	1				1				
49. Ceratium														
N units per ml.	8.2	1.72	16.975	53.348	18.848	3.001	5.254	5.001	4.314	6.979	7.7	1.456	0.55	2.07

Table 9a[1] Individual Plankton Analyses - Below Ft. Randall Dam

	8-19-52	8-27-52	9-4-52	9-10-52	9-17-52	10-1-52	10-8-52	10-15-52	10-21-52	10-29-52	11-5-52	11-12-52	11-18-52	11-26-52	12-5-52	12-11-52
1. Chroococcus																
2. Gomphosphaeria-Coelosphaerium gr								2								
3. Dactylococcopsis							1									
4. Merismopedia																
5. Oscillatoria gr	2														1	
6. Lyngbya gr	1															
7. Rivularia gr						1										
8. Anabaenaceae	2			5	1	3	2	3	5	1	1					
9. Meloseira (a)		16	6	8	62	13	25	4		5	2	1		1		
10. Meloseira (b)		1		3		1		1								
11. Cyclotella-Stephanodiscus gr	18	12	7	56	8	5	10	10	4	3	6	14	10	14	9	5
12. Cyclotella (a)													1	2		1
13. Rhizosolenia gr		7		2	11		4	2	1					1		
14. Fragilaria crotonensis	2	14	1	2	7	8	6	3	1	3	2	3	2			
15. Diatoma vulgare								1								
16. Diatoma elongatum																
17. Asterionella	2				2	3	1	9	3	1	2	5		1	1	
18. Synedra gr	4	7	6	10	9	7	8	12	3	1	7	6	12	12	2	7
19. Pyrosigma gr						1		1	2	1				1		
20. Navicula gr	2	3		4	4	10	7	1	4	2	3	7	11	8		3
21. Cymbella						1						2	1	2		
22. Cyclotella																
23. Rhopalodia								1								
24. Nitzschia gr		1	1	5	4	7	6	3	4	2	5	6	3	1		
25. Cymatopleura solea																
26. Surirella				1			1	2	2			1				
27. Chlamydomonas gr			3	1		1								1	1	1
28. Pandorina morum																
29. Dictyosphaerium														1	1	
30. Schroederia																
31. Staurastrum																
32. Pediastrum duplex	1	5		1	2		1	1		5	2					
33. Pediastrum boryanum																
34. Scenedesmus bijuga	1			2	1		1									
35. Scenedesmus longus																
36. Scenedesmus quadricauda				1	1											
37. Ankistrodesmus																
38. Closterium																1
39. Dictyosphaerium											1					
40. Actinastrum	2	2	1		2		2	1						4	1	2
41. Closteriopsis	2			5	2	3	2	1			1					
42. Tetrastrum																
43. Westella																
44. Pleurotaenium																
45. Lagerheimia																
46. Dimorphococcus																
47. Ceratium						1	1									
48. Schroederia																
49. Coelastrum cambricum																
50. Euglena acus						2										
51. Euglena rostifera	1															
52. Euglena spp.					1			1					1	1	1	1
53. Trachelomonas urceolata				3				1								
54. Trachelomonas spp		2						2	1							
55. Phacus spp.																
56. Dinobryon																
57. Ceratium							1									
# units per c.c.	8.95	31.80	7.00	29.80	55.2	35.67	39.58	16.60	6.39	15.8	10.4	4.58	5.75	4.76	2.72	4.75

Table 44.[illegible] Habitual position analyses - Basin 21 Rhodell Cove (Cores)

	12-16-52	12-24-52	12-31-52	1-5-53	1-14-53	1-21-53	1-27-53	2-4-53	2-10-53	2-18-53	2-25-53	3-4-53	3-10-53	3-18-53	3-25-53	4-1-53
1. Actinocyclus	1				1											
2. Amphiprora-Diploneis gr.				1												
3. Asterionella			1		1											
4. Auricula																
5. Cocconeis gr.																
6. Cyclotella gr.																
7. Fusus gr.									1							
8. Actinocyclus																
9. Melosira (a)									1							
10. Melosira (b)																
11. Cyclotella-Stephanodiscus gr.	1	1		3	1		8									
12. Cyclotella (a)	1															
13. Rhizosolenia gr.	1							1								3
14. Pyxilla cryptocephala																
15. Diploneis vulgaris														1		
16. Diploneis elongata																
17. Asterionella	1			1		1	1			1						1
18. Epithemia gr.	11	9	4	12	11	13	9	6	7	2	1	3	2			
19. Gyrosigma gr.																
20. Navicula gr.	5	1		3	2	1	1		6	1	1					
21. Cymbella									1							
22. Cymatopleura																
23. Rhoicosphenia									1							
24. Nitzschia gr.	1				1	1			6					1	6	2
25. Opephora olsenii																
26. Actinella																
27. Rhoicosphenia gr.	6	5	5	5	6	5	10	12	2	1		2	6	1	2	2
28. Amphora ovalis																
29. Gomphonema		1								12						
30. Gomphonema																
31. Asterionella																
32. Pleurosigma salina									1							
33. Pleurosigma balticum																
34. Amphiprora hyalina																
35. Amphiprora alata									2							
36. Amphiprora cf. paludosa																
37. Diploneis																
38. Achnanthes			1	1		1		3	1							
39. Stephanopyxis																
40. Actinoptychus	1	1	1										2			
41. Cocconeis					1											
42. Tabularia																
43. Navicula																
44. Fragilariopsis																
45. Lauderia																
46. Stephanodiscus																
47. Surirella																
48. Amphiprora						1			1							
49. Auliscus sculptus																
50. Biblos sp.																
51. Biblos rostrata																
52. Biblos sp.	1		2	2	2				2	2		1		1	6	
53. Rhabdonema adriaticum																
54. Rhabdonema sp.	2	1		1									2	1		
55. Fusus sp.																
56. Diploneis											1					
57. Auliscus																
P. delta per ml	0.4	1.04	0.935	1.99	4.49	2.68	1.49	0.671	5.56	1.67	0.909	0.556	1.25	1.5	6.46	1.49

Table 4a) Individual Plankton analyses : Baie St. Paul, Que (Contd.)

	4-8-53	4-15-53	4-28-53	5-6-53	5-13-53	5-20-53	5-27-53	6-3-53	6-10-53	6-24-53	6-24-53	7-8-53	7-15-53	8-5-53	8-12-53	8-19-53	4-1-53
1. Diatomaceae						4	1		1	1		1					
2. Gymnodinoeae-Gymnodinium gr																	
3. Dactylococcopsis	1							1	2								
4. Merismopedia						1	1										
5. Oscillatoria gr.						1	1		4	1						1	
6. Lyngbya gr			2		4	1	10	1									
7. Nostoc gr.				2													
8. Aphanizomenon					1				4		4						
9. Nodularia (a)														69	235	486	1008.0
10. Nodularia (b)														1		2	
11. Spirulina-Arthrospira gr			1			89	61	149	154	12	4	10	382	68	25	18	31
12. Spirulina (a)						24	56	29	7								
13. Rhizosolenia gr	9	1	4		3	4										1	
14. Fragilaria crotonensis	1	1													2	3	4
15. Diatoma vulgare	1																
16. Diatoma elongatum		1	7	2	6		42	6	4								
17. Asterionella	5	1	27	4	24	105	110	30	9								2
18. Synedra gr	2	24	17	2	10	21	7	22	9		2	1		5		1	
19. Cyclotella gr																	1
20. Tabellaria gr	1	7	2		2				2	2	1	1	2	2	1	1	6
21. Cymbella																	
22. Cyclotella																	
23. Rhoicosphenia																	
24. Fragilaria gr	6	22	11		17	5	2	13	18								
25. Cymbella cistula																	
26. Navicula	1	4	14		2	2	1		2				1				
27. Chlamydomonas gr	1	1	11		14	43	9	6	6			5	4		4		2
28. Pediastrum simplex		1				1	1										
29. Dinobryon		1				7	2	1	1							1	
30. Ceratium gr						2											
31. unidentified							1										
32. Pediastrum boryanum						1									1	1	
33. Pediastrum duplex																	
34. Scenedesmus bijuga																	1
35. Scenedesmus dimorphus								1									
36. Scenedesmus quadricauda						2	3	5						2			1
37. Staurastrum																	
38. Asterionella	1	1	6		4	3	24	3	1								
39. Dactylococcus																	
40. Actinastrum						1	2		2				1				
41. Closteriopsis		1							1								
42. Tetrastrum			2														
43. Ceratium						1											
44. Staurastrum						1		1									
45. Lagerheimia					1	1											
46. Staurastrum							4	4									
47. Dinobryon								1	1								
48. Staurastrum												1					
49. Pediastrum Tetras													2	1		2	
50. Euglena sp.																	
51. Euglena proximus																	
52. Euglena spp	1	1	11		7	7	8	4	5		1		4		2		
53. Trachelomonas armata													1				
54. Trachelomonas sp.			3		4	2	9	5	3	1		3	2	3			1
55. Phacus sp.																	
56. Staurastrum						2	5	1									
57. Dinobryon																	
Plants per ml.	2.27	17.5	22.05	2.5	21.87	33.08	53.75	56.66	21.25	1.00	1.868	0.869	14.591	74.439	239.625	673.91	1114.5

Table 9.6 Individual Plankton analyses - Outer Fl. Randall Sea (Contd.)

	9-9-53	9-15-53	9-23-53	9-29-53	10-7-53	10-13-53	10-21-53	10-29-53	11-2-53	11-17-53	11-23-53	11-30-53	12-7-53	12-14-53	12-21-53	12-28-53
1. Chroococcus															2	1
2. Anaphysbaena-Coelosphaerium gr.																
3. Dactylococcopsis																
4. Merismopedia																
5. Oscillatoria gr.				3			4	2		1		1				
6. Lyngbya gr.														1		
7. Rivularia gr.																
8. Aphanizomenon																
9. Nauplius (a)	418	289	68	68	28	13	4	14	6	2	1		1	2		
10. Nauplius (b)	3	1	1	1				1	1			1				
11. Cyclotella-Stephanodiscus gr.	11	12	12	12	16	9	3		1	6	4	3	3	7		
12. Cyclotella (a)																
13. Fragilaria gr.	1		2													
14. Fragilaria crotonensis									1							
15. Diatoma vulgare																
16. Diatoma elongatum														2		
17. Asterionella					1	1						1			13	11
18. Synedra gr.	2		3	2	3	4	2	1	5							
19. Gyrosigma gr.																
20. Navicula gr.	3	1	14	1	2	4	2	1	3	11						
21. Cymbella								1								
22. Cymatopleura																
23. Rhopalodia																
24. Nitzschia gr.					1										1	
25. Cymatopleura solea																
26. Surirella														1		
27. Chlamydomonas gr.		1	1	3	4	25	6	4	9	15	6	7	15	12	10	28
28. Protozoan cocoon				1												
29. Dinocystis	1				2				2			1			2	8
30. Ceratocystis																
31. unidentified																
32. Pediastrum duplex	1	1	1	1												
33. Pediastrum boryanum																
34. Scenedesmus bijuga			1													
35. Scenedesmus limnicus																
36. Scenedesmus quadricauda	1	1	2	1			1					1				
37. Staurastrum																
38. unidentified																
39. Dictyosphaerium												1				1
40. Actinastrum			2						1						1	
41. C. ehrenbergii		2	1	1	4	2	4	1	1	1			2			
42. Tetrastrum														1		1
43. Ankistrodesmus																
44. Micrasterias																
45. Lagerheimia																
46. Dinophysis-type																
47. Ceratia																
48. Favella																1
49. Cleistrum Cambrium																
50. Euplotes vana												1	1			
51. Euplotes rostifera																
52. Euplotes spp		1	1	4	1	2	1	2		1		3	1	2		
53. Tintinnidium spicatum		1			4	1										
54. Tintinnidium spp.			1		1	2				3		2	1	1	1	
55. Phacus spp.																
56. Diophrys																
57. Favella																
# units per ml.	505.08	795.173	204.514	71.99	31.834	15.476	11.17	16.86	8.62	4.519	1.17	2.76	1.35	3.01	4.57	2.64

Table 9[3] Individual Plankton Analyses - Yankton, South Dakota

	8-20-52	8-27-52	9-3-52	9-10-52	9-17-52	9-24-52	10-1-52	10-8-52	10-15-52	10-21-51	10-29-52	11-17-52	11-26-52	12-3-52	12-10-52	12-16-52
1. Chroococcus gr.														2		
2. Gomphosphaeria-Coelosphaerium gr.			252					1				1			1	
3. Dactylococcopsis																
4. Oscillatoria gr.		1									1		2			
5. Spirulina																
6 Lyngbya																
7. Nostoc gr.		1										1				
8. Aphan...emece	2		3		2	5	1			1		1				
9. Melosira (a)	4	5	89	17	71	31	24	34	9	7	2	4	1			
10. Melosira (b)																
11. Cyclotella-Stephanodiscus gr.	23	35	348	98	14	25	14	8	6	5	4	18	13	5	4	2
12. Cyclotella (a)																
13. Rhizosolenia gr.		3	12	6	4	3	6	2	1			1	1			
14. Biddulphia																
15. Fragilaria crotonensis	4	17	19	3	2	14	1	4	3		2	1	1		2	
16. Fragilaria spp.																
17. Diatoma vulgare							1		2				2			
18. Diatoma elongatum																
19. Asterionella		2	6	2		1	1	5	13	4		6	1			
20. Centronella							1									
21. Cerataneis																
22. Synedra gr.	5	5	61	39	15	17	12	10	10	13	8	9	7	4	5	3
23. Rhizosphenia																
24. Cocconeis																
25. Gyrosigma gr.						1			1				1			
26. Navicula gr.	8	3	13		5	3	7	3	12	6	4	13	6	2	4	4
27. Cymbella gr.			1						3				3			
28. Gomphonema gr.																
29. Amphora																
30. Denticula																
31. Cymbopleura													1			
32. Rhopalodia						1		1	1		1				1	1
33. Nitzschia gr.	1	1	13	10	11	10	5	11	26	4	20	8	7		4	
34. Surirella									2		2	2	1			
35. Chlamy...onas gr.			11	8	2	6	1	2	2	3	1	4	1	3	5	3
36. Pandorina																
37. Eudorina																
38. Pleodorina																
39. Oocystis	1					1	1						1	1	1	1
40. Ankistrodesmus			1									1				
41. Pediastrum duplex	2	8	14	4	1		1	1	1		1		1			
42. Pediastrum boryanum			1													
43. Pediastrum integrum	1	1		1						1						
44. Scenedesmus bijuga	2	2	6	6	2	5	1				2	1	1			
45. Scenedesmus dimorphus	2		2			2		1		1						
46. Scenedesmus quadricauda			4													
47. Actinastrum	3	1	14	6	1	2	1		1	3	1			1	2	2
48. Closteriopsis	1		3	5	4		3	5		2					1	
49. Ankyra/eria	1		1							1		2	1			
50. Coelastrum			2													
51. Ankistrodesmus				1	1				1					3		
52. Crucigenia						1										
53. Characium																
54. Tetraedron																
55. Dictyosphaerium																
56. Coelastrum cambricum																
57. Westella																
58. Euglena acus				1	1		1	2								
59. Euglena polymorpha					1											
60. Euglena spp.	1		3	8		1	1	4	2	3		1		1	1	1
61. Trachelomonas urceolata		2		1												
62. Trachelomonas spp.	2			3	2	4	1	1	1	2		1				
N units per ml	17.37	31.2	173.53	48.59	86.45	54.88	31.00	51.06	24.02	16.00	22.28	14.09	19.5	[illegible]892	5.52	1.38

Table. 9[2] Individual cladoton analyses - Yankton, South Dakota (Contd.)

	12-26-52	12-31-52	1-7-53	1-14-53	1-22-53	1-27-53	2-4-53	2-11-53	2-18-53	2-25-53	3-4-53	3-10-53	3-18-53	3-25-53	4-1-53	4-9-53	4-15-53
1. Chroococcus gr.	1	2		3			2										
2. Gomphosphaeria-Coelosphaerium gr.																	
3. Dactylococcopsis																	
4. Oscillatoria gr.																1	1
5. Spirulina																	
6. Lyngbya																	
7. Nostoc gr.																	
8. Aphanizomenon																	
9. Melosira (a)				2													2
10. Melosira (b)																	
11. Cyclotella-Stephanodiscus gr.		1		3		2				1		1	2				
12. Cyclotella (a)				3													
13. Rhizosolenia gr.								1								1	4
14. Biddulphia																	
15. Fragilaria crotonensis		1								1							4
16. Fragilaria spp.																	
17. Diatoma vulgare					1	1	1			1	1		4				6
18. Diatoma elongatum																	
19. Asterionella	1			1	1		2				1	1				1	5
20. Tabellaria																	
21. Ceratoneis																	
22. Synedra gr.	2	4	14	8	8	6	5	6	7	6	2	6			3	2	10
23. Rhoicosphenia																	
24. Cocconeis																	
25. Gyrosigma gr.																	
26. Navicula gr.	5	2	9	3	1	3	5	3	2	1	3	12	8		8	7	19
27. Cymbella gr.		1				2		1	1				2		2		1
28. Gomphonema gr.																	
29. Amphora																	1
30. Denticula																	
31. Cystopleura							1						2				2
32. Rhopalodia												10			3	3	
33. Nitzschia gr.	1	1		2		3	3	2	1	3	1	5	20		7	14	17
34. Surirella									2	2	1						4
35. Chlamydomonas gr.	3	10	7	6	14	8	3	25	2	1	1	4		2	2	2	3
36. Pandorina																	
37. Eudorina																	
38. Pleodorina																	1
39. Gloeocystis														1			1
40. Sphaerocystis																	
41. Pediastrum duplex																	
42. Pediastrum boryanum																	
43. Pediastrum integrum																	
44. Scenedesmus bijuga																	
45. Scenedesmus dimorphus																	
46. Scenedesmus quadricauda																	
47. Actinastrum	1	4	1				1			1							
48. Closteriopsis																	
49. Schroederia																	
50. Coelastis																	
51. Ankistrodesmus					1			1									
52. Crucigenia																	
53. Characium																	
54. Tetraedron																	
55. Dictyosphaerium																	
56. Coelastrum sphaericum																	
57. Westella																	
58. Euglena acus																	
59. Euglena polymorpha																	
60. Euglena spp.	1	4	2	3		1	1	3	1		3	4	2	8	2		2
61. Trachelomonas urceolata																	
62. Trachelomonas spp.		2	1	3													1
N units per ml	1.42	2.11	2.18	4.85	1.18	3.03	3.28	1.94	1.69	3.06	1.83	4.19	3.41	0.854	7.35	12.05	18.8

Table 9:3 Individual Plankton analyses - Yankton, South Dakota (Contd.)

	4-22-53	4-29-53	5-6-53	5-13-53	5-20-53	5-27-53	6-3-53	6-10-53	6-17-53	6-24-53	7-21-53	8-4-53
1 Chroococcus gr.	1	1				2	4					
2. Somphosphaeria-Coelosphaerium gr.												
3. Dactylococcopsis												
4. Oscillatoria gr.	1	5		3	10		6					2
5. Spirulina											1	2
6. Lyngbya												
7. Nostoc gr						52	30					
8. Aphanizomenon												
9. Melosira (a)								1			1	1
10. Melosira (b)				1			4		1		6	37
11. Cyclotella-Stephanodiscus gr.		15		3	71	250	1542	331	17		2	1
12. Cyclotella (a)					25	70	56	9			581	173
13. Rhizosolenia gr.	30	17		2	24							
14. Bidulphia											2	3
15. Fragilaria crotonensis		1			1							
16. Fragilaria spp.												
17. Diatoma vulgare	2	4		2								
18. Diatoma elongatum		4			9	64	110	7				
19. Asterionella	2	34	10	21	142	256	286	23			2	
20. Centronella												
21. Cerataulus												
22. Synedra gr.	18	21	10	13	30	114	68	34			4	3
23. Rhoicosphenia												
24. Cocconeis	1											
25. Gyrosigma gr.												
26. Navicula gr.	13	21	20	19	10	2	4	1				
27. Cymbella gr.		1		3		4	18	14	8		9	
28. Gomphonema gr.												
29. Amphora					1			1				
30. Denticula												
31. Cymatopleura				2								
32. Rhopalodia	1			2				2				
33. Nitzschia gr.	11	24		10	23	90	88	30				
34. Surirella	1	8	10	3	3	6	12	1		2		
35. Chlamydomonas gr.	11	27		3	28	18	24	3		2	2	1
36. Pandorina						12						
37. Eudorina							2					
38. Pleodorina												
39. Gloeocystis	1	7		2	3			1	1			
40. Sphaerocystis												
41. Pediastrum duplex											1	
42. Pediastrum boryanum								1			1	
43. Pediastrum integrum												
44. Scenedesmus bijuga												
45 Scenedesmus dimorphus											1	2
46. Scenedesmus quadricauda							2				2	
47. Actinastrum		1			1	4	16				1	1
48. Closteriopsis						8	10		1		1	
49. Ankistrodesmus							2				1	
50. Coelastis					1	2			1			
51. Ankistrodesmus	2				13	34	72	3			1	1
52. Crucigenia												
53. Characium												
54. Tetraedron												
55. Dictyosphaerium									1			
56. Coelastrum cambricum												6
57. Westella											2	
58. Euglena acus												
59. Euglena polymorpha												1
60. Euglena spp.	4	4	2	8		4	6	2			1	
61. Trachelomonas urceolata												
62. Trachelomonas spp.		4	1		5	4	4	2	2	2	4	
N units per ml.	12.8	30.57	4.92	17.63	63.81	200.09	265.61	44.72	2.51	0.044	38.858	30.443

Table 9: Individual Plankton Analyses - Yankton, South Dakota (Contd.)

	8-18-53	9-1-53	9-9-53	9-15-53	9-29-53	10-7-53	10-13-53	10-21-53	10-29-53	11-4-53	11-17-53	11-23-53	11-30-53	12-7-53	12-14-53	12-21-53	12-28-53
1. Chroococcus gr.																	
2. Gomphosphaeria-Coelosphaerium gr.																	
3. Dactylococcopsis	1			1													
4. Oscillatoria gr.							5			3						1	
5. Spirulina																	
6. Lyngbya																	
7. Nostoc gr.																	
8. Aphanizomenon		1		1							1						
9. Melosira (a)	1255	3024	1886	843	210	158	37	7	23	9	3	4	5	4	1	3	1
10. Melosira (b)	4	1	1	3						4							
11. Cyclotella-Stephanodiscus gr.	40	44	52	68	30	21	15	8	6	5	6	1	4	2	3	3	1
12. Cyclotella (a)																	
13. Rhizosolenia gr.	1				3	2									1		
14. Biddulphia																	
15. Fragilaria crotonensis	1	6	1			1											
16. Fragilaria spp.	1					2		2	2	7			3	1	1		
17. Diatoma vulgare															1		
18. Diatoma elongatum															2	1	
19. Asterionella		2				1	1	4	1		1	1			1	5	19
20. Centronella																	
21. Cerotoneis																	
22. Synedra gr.					1	2	4	1	2	3							
23. Rhoicosphenia										1							
24. Cocconeis																	
25. Cymatopleura gr.																	
26. Navicula gr.	12	3	1		7	7	11	11	23	32	2	14	10		4	3	1
27. Cymbella gr.							1		3	4							
28. Gomphonema gr.																	
29. Amphora																	
30. Denticula													1				
31. Cymatopleura																	
32. Rhopalodia						2	1	1	2	12	1		6	1	2		
33. Nitzschia gr.						3	1	1		9		7	8	5	6	1	
34. Surirella							1		1								
35. Chlamydomonas gr.				5	5		7		8		4	4		1	3	5	4
36. Pandorina							1										
37. Eudorina																	
38. Pleodorina																	
39. Gloeocystis	1	2	5	2			4								2		
40. Sphaerocystis																	
41. Pediastrum duplex	3	2	1	2		1											
42. Pediastrum boryanum																	
43. Pediastrum integrum																	
44. Scenedesmus bijuga				1		1	1			1		1					
45. Scenedesmus dimorphus		2								1							1
46. Scenedesmus quadricauda	1	1	1	2		1									1		
47. Actinastrum	2			1				1									
48. Closteriopsis							4	3		3		1					
49. Schroederia																	
50. Coelastis	1																
51. Ankistrodesmus																	
52. Crucigenia	1																
53. Closterium																	
54. Tetraedron																	
55. Dictyosphaerium	7	14	1	2													
56. Coelastrum cambricum	3		1														
57. Westella		1															
58. Euglena acus																	
59. Euglena polymorpha																	
60. Euglena spp.					1					1		2					
61. Trachelomonas urceolata				1													
62. Trachelomonas spp.	1			1			1										
N units per ml.	1247.299	3036.778	1891.09	854.755	211.887	167.45	68.94	12.462	26.456	35.126	6.269	10.9	12.424	7.75	8.306	6.25	5.96

Table 9[3] Subtidal Plankton Analyses - Oahu, Hawaii

	8-21-52	9-9-52	9-25-52	10-16-52	10-29-52	11-14-52	11-29-52	12-8-52	12-22-52	12-31-52	1-16-53	2-2-53	2-6-53	2-23-53	3-12-53	3-24-53
1. Chroococcus gr.											1					
2. Camphosphaeria-Coelosphaerium gr.	1						2									
3. Dactylococcopsis																
4. Oscillatoria gr.																
5. Nostoc gr.							1									
6. Aphanizomenon		1	6	3				1								
7. Nitzschia (a)	1	35	20	20										5		
8. Nitzschia (b)																
9. Cyclotella-Stephanodiscus gr.		61	31	13	3	15	9	5		4				1	1	
10. Cyclotella (a)							9	169	221	186				5		
11. Rhizosolenia gr.							3	4	2	3						
12. Fragilaria crotonensis		2	3	6	1	1	1									
13. Fragilaria spp.																
14. Diatoma vulgare						1	1	2							3	
15. Asterionella		1		2				1					3	2	2	
16. Synedra gr.		2	5	14	2	3	8	6	3	4	6	2	3	2	2	
17. Cocconeis																
18. Cymatopleura gr.	2		1		1									1	4	
19. Navicula gr.	1	1	4	7	2	7	10	5	6		3		3	1	20	
20. Cymbella gr.			1			1									1	
21. Amphora															2	
22. Gyrosigma																2
23. Rhopalodia					1	2										
24. Mitzschia gr.		3	5	8	9	6	4	3		1			3	4	78	8
25. Surirella		1			2	1	1							1	5	
26. Chlamydomonas gr.	4	2	4	4	2	7	1	3	22	12	7	3	2	3		6
27. Dictyosphaerium		1		2		1	1	3								
28. Schroederia																
29. Pediastrum duplex	2	2	5	1		1	1									
30. Staurastrum bieje		2														
31. Staurastrum dimorphum	2	1		2				1								
32. Staurastrum quadricauda			2	1												
33. Staurastrum arcuatum																
34. Actinastrum		1		2				1	1	1						
35. Closteriopsis		2					1									
36. Planktosphaeria		2														
37. Ankyrodesmus			1				1									
38. Ankistrodesmus							1	5	4	3						
39. Dictyosphaerium																
40. Coelastrum cambricum																
41. Euglena acus																
42. Euglena polymorpha		2	3	3												
43. Eu. sus spp.							2		7	14	4	2		2	2	4
44. Euglena deutschia	1															
45. Trachelomonas urceolata			1													
46. Trachelomonas spp.		1		1	2	2			1	1						4
47. Phacus spp.	2															
N units per ml	7.91	47.5	45.2	35.05	6.93	6.91	8.60	5.13	2.20	3.36	1.23	0.427	2.68	9.20	49.81	5.41

Table 4. Individual Plankton Analyses - Omaha, Nebraska (Cont'd.)

	4-10-53	4-23-53	5-11-53	5-30-53	6-13-53	10-14-53	10-21-53	10-28-53	11-4-53	11-11-53	11-18-53	11-25-53	12-2-53	12-9-53	12-16-53	12-23-53	12-30-53
1. Chroococcus gr.				2		gr.											
2. Gomphosphaeria-Coelosphaeriu																	
3. Dactylococcopsis		1															
4. Oscillatoria gr.		2		82	1	2			1		1						
5. Nostoc gr.																	
6. Anarthron.m	5			10	6	28	4	2	3	7				1			
7. Melosira (a)	8	7		34		76	37	24	10	11	6	7	5	4	4	2	1
8. Melosira (b)					1	3		1		2		1					
9. Cyclotella-Stephanodiscus gr.		9	20	360	44	31	26	16	17	12	16	16	17	10	11		3
10. Cyclotella (a)		46		30							12	10	3	4	13		
11. Rhizosolenia gr.	4	29					1	1	2	1	3	2	2				
12. Fragilaria crotonensis		2		7										1			
13. Fragilaria spp.						3	3	1		2	2	2	3	2	1		
14. Diatoma vulgare	1	3	10	176								1		1			
15. Asterionella		16	100	300	2	3	6	5		3	1			2			2
16. Synedra gr.	4	15	50	150	3	2	4	9	5	12	4	10	1	1			2
17. Cocconeis						1						1					
18. Gyrosigma gr.	1					1	2	1	2						1		
19. Navicula gr.	2	11	40	24	6	5	19	15	10	16	4	15	5	1	6	1	2
20. Cymbella gr.		1		2													
21. Amphora																	
22. Cyclotella							1										
23. Nitzschia gr.	10		20	50		1	2	1		1	8	7	13	5	4	1	2
24. Surirella	1	4	10	4						1		1	1	1			
25. Chlamydomonas gr.	5	8		4	2	2	2	6	13	4	25	39	109	16	5	11	35
26. Dictyosphaerium	1	2					4	9	1								
27. Dinobryon sertularia				2													
28. Pediastrum duplex								1		1							
29. Scenedesmus bijuga							1		2								
30. Scenedesmus dimorphus				6					2		1						
31. Scenedesmus quadricauda				10				2									
32. Scenedesmus serratus																	
33. Actinastrum				2		7	1	4	4	16	2	3	1		1		
34. Closteriopsis						2	9	1	4		1				1		
35. Ankistrodesmus																	
36. Elakatothrix										1							
37. Botryococcus																	
38. Kirchneriella		4		10								2					
39. Dictyosphaerium				2													
40. Coelastrum cambricum																	4
41. Euglena acus																	
42. Euglena polymorpha																	
43. Euglena spp.		4		6	1											1	
44. Euglena oxyuris																	
45. Trachelomonas crebolata																	
46. Trachelomonas spp.	1			2	2	1	1									1	
47. Phacus spp.																	
48. Mallomonas		2					2	1	2	1	2		4	1	1		
N. Units per ml.	16.25	19.26	37.4	293.34	5.54	8	46.3	34.477	20.43	10.975	16.1	17....	16.75	9.34	0.1...	2.49	7.67

Table 10. Phytoplankton Concentration (No. per ml.), Niobrara River at Niobrara, Nebraska

	7-1-53	9-25-53
BLUE-GREEN ALGAE		
Chroococcus		6
Dactylococcopsis		1
Microcystis aeruginosa	15	
Oscillatoria gr.		4
Aphanizomenon		1
DIATOMS		
Cyclotella-Stephanodiscus gr.	7	54
Melosira (b)		2
Rhizosolenia gr.	15	1
Fragilaria crotonensis	1	
Fragilaria spp.		3
Synedra gr.	7	41
Navicula gr.	61	135
Rhopalodia	1	5
Nitzschia gr.		2
GREEN ALGAE		
Chlamydomonas gr.		143
Pandorina morum		2
Tetraspora		2
Gloeocystis	34	2
Pediastrum boryanum	40	3
Pediastrum duplex	14	1
Scenedesmus dimorphus	327	1
Scenedesmus quadricauda	54	14
Scenedesmus bijuga	40	8
Crucigenia	2	
Actinastrum	94	1
Westella	34	2
Schroederia	15	
Dictyosphaerium	1,352	2
Ankistrodesmus	7	6
Tetraedron	1	
Coelastrum cambricum	1	
Trochiscia aspera		67
Staurastrum	3	
Cyclotheca		2
Total No. per ml	2,135	552

Table 11. Phytoplankters in Net Samples - No. per liter

	Chamberlain				Below Ft. Randall Dam				Yankton			
	1-27-53	3-11-53	4-23-53	5-29-53	1-27-53	3-10-53	4-22-53	5-28-53	1-27-53	3-10-53	4-23-53	5-28-53
Chroococcus						5	12	10	4		4	50
Gomphosphaeria-												
Coelosphaerium gr.								10				30
Merismopedia								10				
Dactylococcopsis				10			16	1			12	
Oscillatoria gr.				20				10				30
Lyngbya				70				10				20
Spirulina										1		
Aphanizomenon				10								
Melosira (a)												
Cyclotella-												
Stephanodiscus gr.	4				8	1		900	8		4	1,200
Cyclotella (a)				100				290				160
Rhizosolenia gr.	4			250				70			68	100
Biddulphia				10						1		
Diatoma vulgare		1						10	4	1	28	10
Diatoma elongatum				1,080			32	3,893			12	4,570
Fragilaria crotonensis	8	6	448	140	8		24	60	4	3	24	160
Synedra gr.	24	7	188	40	28	5	128	110	24	3	76	60
Cocconeis				30								20
Cerataneis											4	
Asterionella	8	3	1,532	340	12	1	552	38,385	8	1	128	82,485
Navicula gr.	12	1	68	40	8	2	32		20	8	80	20
Cymbella			24		4		8					
Cymatopleura										1		
Nitzschia gr.		4	72	200		2	36	50		10	116	130
Surirella			8					20		2	12	50
Chlamydomonas gr.	24	4	4	60	8	3	24	70	12	5	32	80
Pandorina							16	40				110
Pleodorina											4	
Gloeocystis		1					8	10			8	50
Pediastrum duplex							4	40	8		8	70
Pediast. boryanum								10				
Scenedesmus -												
dimorphus								10				
Scene. quadricauda			4			1		20				
Actinastrum				40				50				20
Characium											4	
Ankistrodesmus				50		1	4	70		1		20
Schroederia						1						
Westella								10				
Euglena sp.	4	5	24	20		2	48	130	8	3	20	10
Euglena acus								10				
Trachelomonas sp.	8		12	10					12		24	30
Dinobryon							4	270				310
Ceratium	8			10	8	2			12			
Total No. per liter	104	32	2,344	2,530	84	26	948	44,579	124	40	668	89,795

Table 12. Vertical Distribution of Zooplankters, Fort Randall Reservoir, August 4 and September 1, 1953. Nos. per Liter.

	Surface		5 feet		15 feet		30 feet	
	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.
Rotifers:								
Polyarthra platyptera	20	-	20	10	10	-	-	-
Keratella quadrata	-	10	-	40	-	10	-	-
Keratella cochlearis	-	20	-	10	-	10	-	-
Copepods:								
Diaptomus	10	-	-	-	-	-	-	-
Cyclops sp.	-		40	20	-	20	-	-
Nauplii	140	90	50	120	160	160	150	140
Cyclopoids	30	10	30	20	70	80	80	120
Cladocerans:								
Bosmina sp.	40	40	40	20	20	30	30	60
Ceriodaphnia sp.	10	-	10	-	-	-	-	-
Daphnia longispina	-	20	10	-	-	-	-	-

Table 13[illegible] Individual Plankton Analyses - Pt. Pinkill Reservoir

	7-21-53	8-4-53	8-11-53	8-18-53	9-1-53	9-9-53	9-15-53	9-23-53	9-29-53	10-7-53	10-13-53	10-21-53	10-29-53	11-2-53	11-17-53
1. Chroomonas		2	1		2					1	1	1			
2. Cryptomonas-Cyclotella		1													
3. Dactylococcopsis			2						1						
4. Oscillatoria gr.									2	9	5				
5. Lyngbya															
6. Anabaenopsis															
7. Melosira (b)	2						3	3		1					
8. Melosira (a)	3	6	16	514	696	350	496	170	97	32	35	9	15	16	6
9. Cyclotella-Stephanodiscus gr.	108	66	54	27	23	25	27	62	25	14	9	1	2	6	3
10. Meloseirella gr.	2			1				2	1	1		1			
11. Diatoma elongatum	1														
12. Fragilaria crotonensis				1		2									
13. Tabellaria fenestrata															1
14. Asterionella formosa										1	3	1			
15. Synura gr.	2				1	1	3	5	2	2	3	11	1	2	
16. Dinobryon gr.								1							
17. Rhizosolenia gr.	6	2	3	2		1	4	6	10	4	14	9	5	4	3
18. Cyclotella gr.										1		1			
19. Chlamydomonas gr.	13	4	2		4		2		4	16	83	16		9	3
20. Dinobryopsis gr.						1			1		4			2	1
21. Ceratocystis												1			
22. Pediastrum boryanum			2				1								
23. Botryella gr.															
24. Staurastrum dejup				1		1	1			1				2	
25. Staurastrum paradoxum							2		1		2	1			1
26. Staurastrum dimorphum	1		1						1						
27. Ankistrodesmus setigerus	4														
28. Actinastrum hantzschii	1							1				4			
29. Closteriopsis longissima			1				2		3	1		2		1	
30. Closterium moniliferum							1			1	1				
31. Closterium gracilentum					1										
32. Dictyosphaerium															
33. Tetraedron										1					
34. Chlorella															
35. vorticella															
36. Euglena sp.	11		4	2	4			2	5	1	5	5			2
37. Euglena acus	1													1	
38. Phacus	1														
39. Trachelomonas sp.	19	4	2		1				2	1	2	4		1	
40. Trachelomonas volvocina	2							1							
# UNITS OF VOL.	21,140	3.71	100.7	540.875	696.25	325.96	396.02	110.59	100.871	44.000	45.1	43.4	15.48	19.337	7.54

Table 11[2] Individual Plankton Analyses - Ft. Randall Reservoir (Cont'd.)

	11-23-53	11-30-53	12-7-53	12-14-53	12-21-53	12-28-53
1. Chroococcus						1
2. Gomphosphaeria-Coelosphaerium						
3. Dactylococcus sp.						
4. Oscillatoria gr.						
5. Lyngbya				1		
6. Aphanizomenon	1		1			
7. Melosira (b)						1
8. Melosira (a)	5			2		
9. Cyclotella-Stephanodiscus gr.	4	2	7	5	4	
10. Botryococcus gr.						
11. Diatoma elongatum				2	1	
12. Fragilaria crotonensis						
13. Tabellaria fenestrata						
14. Asterionella formosa		1		1	6	9
15. Synedra gr.					1	
16. Gyrosigma gr.						
17. Navicula gr.						
18. Cymbella gr.						
19. Surirella gr.				1		
20. Chlamydomonas gr.	6	3	7	16	20	37
21. Glenocystis gr.				4		2
22. Sphaerocystis						
23. Pediastrum duplex						
24. Scenedesmus bijuga						
25. Scenedesmus quadricauda	1					1
26. Scenedesmus dimorphus						
27. Ankrodesmus falcatus						
28. Actinastrum hantzschii						
29. Closteriopsis longissima						
30. Coelastrum cambricum						
31. Coelastrum proboscideum						
32. Dictyosphaerium	1			1	2	
33. Tetrastrum						
34. Chlorella			1			
35. Westella			1			
36. Euglena spp.		1	1	1		
37. Euglena acus						
38. Phacus						
39. Trachelomonas spp.	1	1	1	1		
40. Trachelomonas urceolata						
# units per ml.	6.308	0.397	0.503	3.485	1.73	2.91